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A COMPARISON OF THE PROTECTION AGAINST IMMERSION HYPOTHERMIA PROVIDED BY COAST GUARD ANTI-EXPOSURE CLOTHING IN CALM VERSUS ROUGH SEAS

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16. Abstract
The purpose of this study was to compare the protection against immersion hypothermia provided by various types of Coast Guard operational clothing to survivors of mishaps in calm versus rough seas. Eight garment ensembles were evaluated: 1) flight suit (control); 2) full wet suit and 3) shorty wet suit (tight-fitting "wet" garments); 4) aviation anti-exposure coveralls, 5) boatcrew anti-exposure coveralls, and 6) thermal float coat (loose-fitting "wet" garments); 7) dry suit, 8) survival suit ("dry" garments). Mean calm-water temperature was 10.7 °C. Rough-water mean temperature was 11.1°C. with 4-6 foot swells, occasional 4-foot breaks, 2-3 foot wind-waves and 0-3 knots current. Eight volunteer Coast Guard crewmen wore each garment-ensemble once in each of the two sea conditions. Dependent variables were rectal temperature, groin skin temperature, back skin temperature, heart rate, and subjective evaluations of warmth, tightness of garment fit, and amount of cold water flushing. The results showed significantly faster mean rectal temperature cooling rates and significantly larger declines in skin temperatures in rough seas than in calm seas for subjects wearing the float coat, aviation anti-exposure coveralls and boatcrew coveralls. Heart rates were significantly faster in rough seas than in calm seas for all garments. Rectal and skin temperature changes were positively correlated with each other and with subjective evaluation of cold water flushing, but they were negatively correlated with warmth and tightness of fit. In general, "dry" garments provided better protection than did "wet" garments in both sea conditions, and tight-fitting "wet" garments provided better protection than did loose-fitting "wet" garments in rough seas, but not in calm seas. These results demonstrate that survivors in rough seas may have significantly greater risk from immersion hypothermia than previously assumed based on survival time projections from calm-water studies.

17. Key Words
Hypothermia
Immersion
Protective clothing
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PREFACE

This study is the first of a three-part effort to improve the operational clothing worn by Coast Guard aircrew, boatcrew and cutter personnel. Subsequent studies will evaluate the degree of protection against cold wind and spray when operational clothing is worn in foul weather, and the degree of heat stress produced when the clothing is worn in a warm, humid environment.

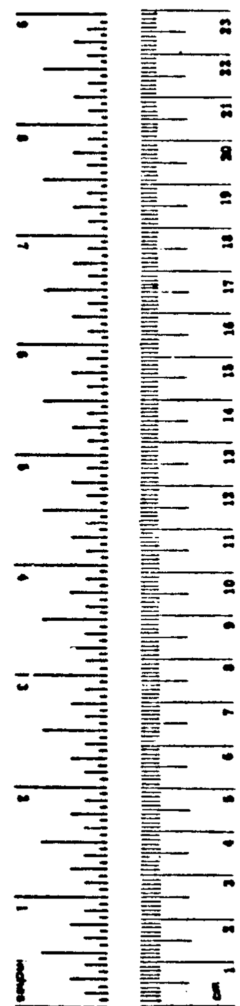
This study was accomplished only through the extraordinary efforts of many Coast Guard men and women who focused their talents, ingenuity and diligence on its successful completion. The authors wish to thank the Commanding Officer and personnel of Coast Guard Station Cape Disappointment, of the National Motor Lifeboat School and of Coast Guard Air Station Astoria, all of whom generously provided their resources for the six weeks necessary to complete the tests. In particular we wish to acknowledge the contributions of BM1 Curtis Mauck, CGSTA Cape Disappointment, whose skills in boat-handling, problem-solving and organization were the primary reason the project was completed without mishap. We also wish to thank LCDR Tom Meyer, CCGD13 (osr) for his coordination of the many Thirteenth Coast Guard District efforts required to support this study, LT(jg) Don Taube, COMDT (G-DST), for his coordination of Headquarters support, and the Office of Research and Development which provided the funding for this project. Finally, we want to acknowledge the ten Coast Guard volunteers who served as subjects for this study. Each of these men willingly endured both a significant amount of discomfort and a degree of risk during their sixteen cold-water immersions over the course of the experiment.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

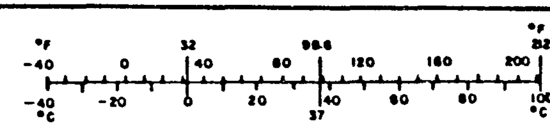
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The protection provided by anti-exposure garments against heat loss from immersion in cold water is of interest to both military and civilian maritime personnel. Previous studies on the cooling rates of human volunteers wearing various types of protective clothing have generally been conducted in calm water (1-9). Mishaps involving immersion hypothermia, however, often occur in rough water, yet scientific data on human cooling rates in rough seas are not available.

A survivor's primary problem in rough seas is maintenance of airway freeboard; hypothermia is only of secondary importance (5,10,11). The activity required to maintain airway freeboard, however, even when a life jacket or other buoyant device is worn, may increase a survivor's cooling rate by increasing peripheral circulation and consequently decreasing effective tissue insulation. Hayward et al. showed large differences in the cooling rates of human volunteers between swimming and holding-still in relatively calm water (12). Cannon and Keatinge showed similar increases in cooling rates among subjects of varying fatness when exercising in calm water (13). Nadel et al. showed that even in the absence of active swimming, increased heat loss occurred in rough seas due to passive movements of the swimmers by wave action (14). As the seas became more rough, more physical activity was required by the swimmers to maintain airway freeboard, thus further increasing heat loss. Furthermore, if a survivor's anti-exposure garment requires the maintenance of a warm layer of trapped water as part of its insulation (e.g. "wet" protective garments such as wet suits or foam-insulated coveralls), and if the survivor's movements to maintain his airway freeboard result in flushing of this trapped warm water by ambient cold water, the survivor's cooling rate may increase.

The purpose of this study was to evaluate cooling rates and skin temperatures of human volunteers, dressed in various types of Coast Guard operational protective garments, in cold sea-water under calm versus rough sea conditions. The hypothesis was that rough seas would be associated with lower skin temperatures and faster cooling rates.

MATERIALS AND METHODS

A. Experimental Design

The experimental design was a cross-over study in which eight subjects wore each of eight different garment ensembles in both calm and rough water conditions. An eight-subject by eight-garment testing matrix was thus established for both calm-water and rough-water experimental blocks. Garment ensembles were tested in random order by each subject within the calm and rough water blocks. But randomization between calm and rough water blocks was not possible because of the unpredictability of rough water conditions. Therefore rough water tests were performed whenever the sea state was appropriate; calm water tests were performed in the interim periods. Due to the relative infrequency of appropriate rough water conditions, the calm water tests were completed earlier in the study than the rough water tests.

Each subject was immersed only once per day in order to ensure re-equilibration of physiological homeostasis between tests. The eight subjects were divided into two groups which alternated between morning and afternoon immersions.

The dependent variables in this study were: 1) rectal temperature; 2) groin skin temperature; 3) back skin temperature; 4) heart rate; and 5) subjective evaluation of garment-ensemble performance. The independent variables were 1) garment-ensemble; and 2) sea state.

B. Subjects

Approval for the use of human subjects was given by the Chief of Operational Medicine (COMDT (G-KOM)), the Chief of Safety Programs (COMDT (G-CSP)) and the Chief of Search and Rescue (COMDT (G-OSR)) following a review of a risk/benefit analysis of the experiment (Appendix A). The risk/benefit analysis and the approval procedures met the legal requirements of both the Coast Guard and the Department of Transportation for human experimentation (Appendix B). The use of human subjects in this study also conformed to the Recommendations from the Declaration of Helsinki on human experimentation (15).

The subjects were eight active-duty, male Coast Guard volunteers, each with extensive experience as either helicopter or lifeboat crewmen. They were selected on the basis of anthropometric similarity, swimming skills and physical fitness. Prior to selection each subject read and signed an informed consent document (Appendix C). The eight volunteers were not representative of the average Coast Guard male population.

Because of the risks involved in this study, subjects were required to demonstrate better than average physical fitness, swimming ability and competence in rough sea conditions. In addition, the volunteers had less percent body fat than the average Coast Guard male. A complete physical examination and maximum treadmill stress test were performed on each subject prior to the start of the study. The subjects are shown in Figure 1.

Anthropometric data on the subjects are shown in Table 1. Skinfold thicknesses were measured with a Harpenden calipers. Percent body fat was calculated according to the method of Yuhasz (16). Somatotypes were calculated according to the method of Heath-Carter (17). Buoyancy requirements were measured by weighing the subjects while immersed in water to the level of a horizontal line between the ear lobe and the tip of the chin (18).

TABLE 1. PHYSICAL CHARACTERISTICS OF THE EIGHT SUBJECTS

Subject	Age (yrs)	Weight (kg)	Height (cm)	Skinfold Thickness (mm)(a)	Body Fat (%)	Somatotype(b) Endo	Meso	Ecto	Buoyancy Required (kg)(c)
1	27	75.2	174.8	14.0	14.4	3.5	6.0	1.5	5.9
2	21	65.0	169.7	9.9	11.9	2.5	5.0	2.5	5.6
3	33	77.7	178.3	8.5	11.0	2.0	5.5	2.0	7.2
4	25	70.0	172.7	7.2	10.2	2.0	5.5	2.0	5.3
5	22	69.0	173.4	8.0	10.7	2.5	4.5	2.5	5.9
6	22	73.7	177.8	8.8	11.2	2.5	5.0	2.5	6.3
7	24	74.2	174.9	11.7	13.0	3.0	5.5	2.0	6.8
8	20	72.6	174.0	12.9	13.7	3.5	5.0	2.0	6.0
Means	24.3	72.2	174.4	10.1	12.0	2.7	5.3	2.1	6.1
S.D.	4.2	4.0	2.8	2.5	1.5	0.6	0.5	0.3	0.6

(a) Mean of four sites: triceps, subscapular, suprailiac, abdominal
(b) Dimensionless quantities: Endo = endomorphy (relative fatness);
Meso = mesomorphy (relative musculo-skeletal mass);
Ecto = ectomorphy (relative lankiness).
(c) Flotation necessary to maintain airway freeboard

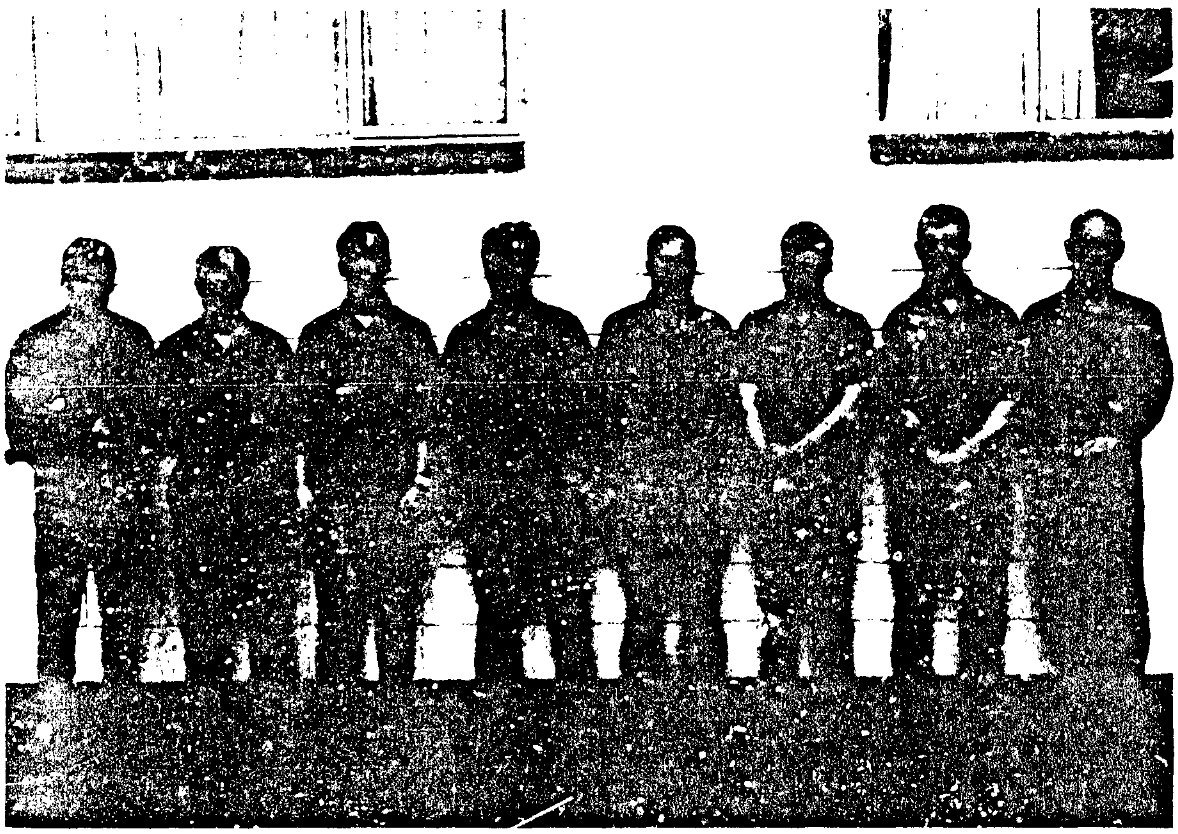

Figure 1. Experimental Subjects

C. Garment-Ensembles

The eight garment-ensembles in this study represent a sample of cold-weather clothing worn by crewmen on Coast Guard operational missions. The eight garment-ensembles are grouped as follows: 1) one control; 2) five "wet" ensembles (i.e. allowing skin contact with cold water); and 3) two "dry" ensembles (i.e. preventing skin contact with cold water). The items of clothing comprising each ensemble represent the most frequently used configuration. The eight garment-ensembles are listed in Table 2, and a brief description of each garment is provided below:

1) Flight Suit: This is the standard aviation coverall worn by military helicopter crews. Its Military Supply Catalog designation is "Coveralls, Flyers, Summer, Fire-Retardant; MILC-83141A." It is a single-piece coverall made of Aramid III (Nomex), fire-retardant material. It has minimal insulation and served as a control garment in these tests. Figure 2 shows the flight suit ensemble.

2) Wet Suit: This "wet" garment is widely used by aircrewmen, boatcrewmen, boarding parties and ship deck personnel. It consists of an upper and lower piece of 3/16" Neoprene closed-cell foam. The upper piece fits snugly over the trunk and arms and has a beaver-tail for ensuring tight fit around the groin. The lower piece fits snugly over the lower extremities. An attached 3/16" Neoprene hood is worn for head protection. The model designation of the wet suit is "1416 custom" from Imperial Manufacturing Co., Bremerton, WA. Figure 3 shows the wet suit ensemble without the inflatable life vest.

3) Shorty Wet Suit: This "wet" garment-ensemble is designed for aircrew personnel flying over moderately cold water in warm, humid air temperatures (e.g. Gulf Coast in Spring). It consists of 1/8" Lycra covered closed-cell foam with a terry-cloth lining. It fits snugly over the trunk, arms and upper thighs. It is worn over cotton underwear but underneath a flight suit. A separate 1/8" Neoprene closed-cell foam hood is worn underneath the flight helmet. The model designation is "Coast Guard Custom Shorty", and the manufacturer is Henderson Aquatics of Milville, NJ. Figure 4 shows the shorty wet suit alone, and Figure 5 shows the complete shorty wet suit ensemble.

4) Aviation Coveralls: This "wet" garment-ensemble is intended for helicopter personnel flying over water colder than 60 degrees F. It is a loose-fitting coverall with an inner and outer lining of Aramid III fire-retardant material. Its insulation consists of 1/8" PVC foam throughout. A separate 1/8" Neoprene closed-cell foam hood is worn underneath the flight helmet. Its model designation is "MAC-10." Its manufacturer is Mustang Industries, Vancouver, British Columbia. Figure 6 shows the coveralls without flight helmet or inflatable life-vest.

TABLE 2. ANTI-EXPOSURE GARMENT-ENSEMBLES

Test Garment	Underwear	Head Covering	Hand Covering	Foot Covering	Additional Flotation
CONTROL					
1) Flight suit	Cotton thermal(a)	Flight helmet	Flight gloves(b)	Wool socks; Flight boots	Inflatable life-vest (LPU-25/P)
"WET" GARMENTS					
2) Wet suit	Cotton shirt and shorts(c)	Wet suit hood	Wet suit gloves	Wool socks; Flight boots	Inflatable life-vest (LPU-25/P)
3) Shorty wet suit (under a flight suit)	Cotton shirt and shorts	Wet suit hood under a flight helmet	Flight gloves	Wool socks; Flight boots	Inflatable life-vest (LPU-25/P)
4) Aviation Coveralls	Cotton thermal	Wet suit hood under a flight helmet	Flight gloves	Wool socks; Flight boots	Inflatable life-vest (LPU-25/P)
5) Boatcrew Coveralls	Cotton uniform; Cotton shirt and shorts	Wool watch cap under garment's insulated hood	Leather gloves(d); wool inserts	Wool socks; Flight boots	Inflatable pillow from coveralls
6) Thermal float coat	Cotton uniform; Cotton shirt and shorts	Wool watch cap under garment's uninsulated hood	Leather gloves(d); wool inserts	Wool socks; Flight boots	None
"DRY" GARMENTS					
7) Dry suit (e)	Cotton thermal	Garment's insulated hood	Garment's insulated gloves	Wool socks; Insulated boots	None
8) Survival suit (e)	Cotton uniform; Cotton shirt and shorts	Garment's insulated hood	Garment's insulated gloves	Wool socks; Flight boots; Insulated boots	Garment's inflation ring

(a) Common, lightweight "long-johns" from J.C. Penneys
(b) Military Supply Designation: Gloves, Flyers, Nomex; #8415-00-139-5410
(c) Tee-shirt and briefs from J.C. Penneys
(d) 1/8" thick gloves
(e) Insulated hood, gloves and boots are an integral part of this garment

5) Boatcrew Coveralls: This "wet" garment-ensemble is widely used by lifeboat and ship-deck personnel working over cold water in foul weather. It is a loose-fitting coverall with varying thicknesses of PVC foam, as follows: anterior chest, 5/8"; back, 5/16"; anterior abdomen, 5/16"; sleeves, 3/16"; upper legs, 3/16". It has a Nylon, waterproof outer shell and an attached hood insulated with 1/4" PVC closed-cell foam. It is worn over the Coast Guard working blue uniform (Figure 7). Its model designation is "IFS-580." It is made by Stearns Manufacturing, St. Cloud, MN. It is illustrated in Figure 8.

6) Thermal Float Coat: This jacket is worn by lifeboat and ship deck personnel working over cold water in foul weather. It is a "wet" garment-ensemble consisting of Nylon inner and outer layers enclosing 3/8" Ensolite closed-cell foam insulation anteriorly and 1/8" foam posteriorly and in the sleeves and lower back. In addition it has an 1/8" closed-cell foam beaver-tail for groin insulation and for securing the jacket around the trunk. An attached, uninsulated hood is worn over a wool watch cap. The Float Coat is worn over the Coast Guard working blue uniform. Its model designation is "UVic Thermofloat." Its manufacturer is Mustang Industries, Vancouver, British Columbia. Figure 9 shows the float coat.

7) Dry Suit: This "dry" garment-ensemble is intended for vessel crewmen working in cold climates over cold water. It consists of a loose-fitting, one-piece, 3/16" Neoprene closed-cell foam, watertight coverall (including integral rubber boots) with pliable, soft, watertight wrist and neck seals. A detached 1/8" Neoprene closed-cell foam hood and detached 1/8" Neoprene closed-cell foam gloves are also provided. Its model designation is E38-001. Its manufacturer is Narwhal Marine, LTD, Bedford, MA. It is shown in Figure 10.

8) Survival Suit: This "dry" garment-ensemble is intended for emergency use in vessel capsizings or sinkings or in helicopter ditchings. It is a one-size-fits-all coverall with integral hood, boots and gloves. It consists of 3/16" Neoprene closed-cell foam throughout with an additional inflation ring around the chest. It is worn over the Coast Guard working blue uniform. It is made by Imperial Manufacturing, Bremerton, MA. It is shown in Figure 11.

Figure 2. Flight suit ensemble

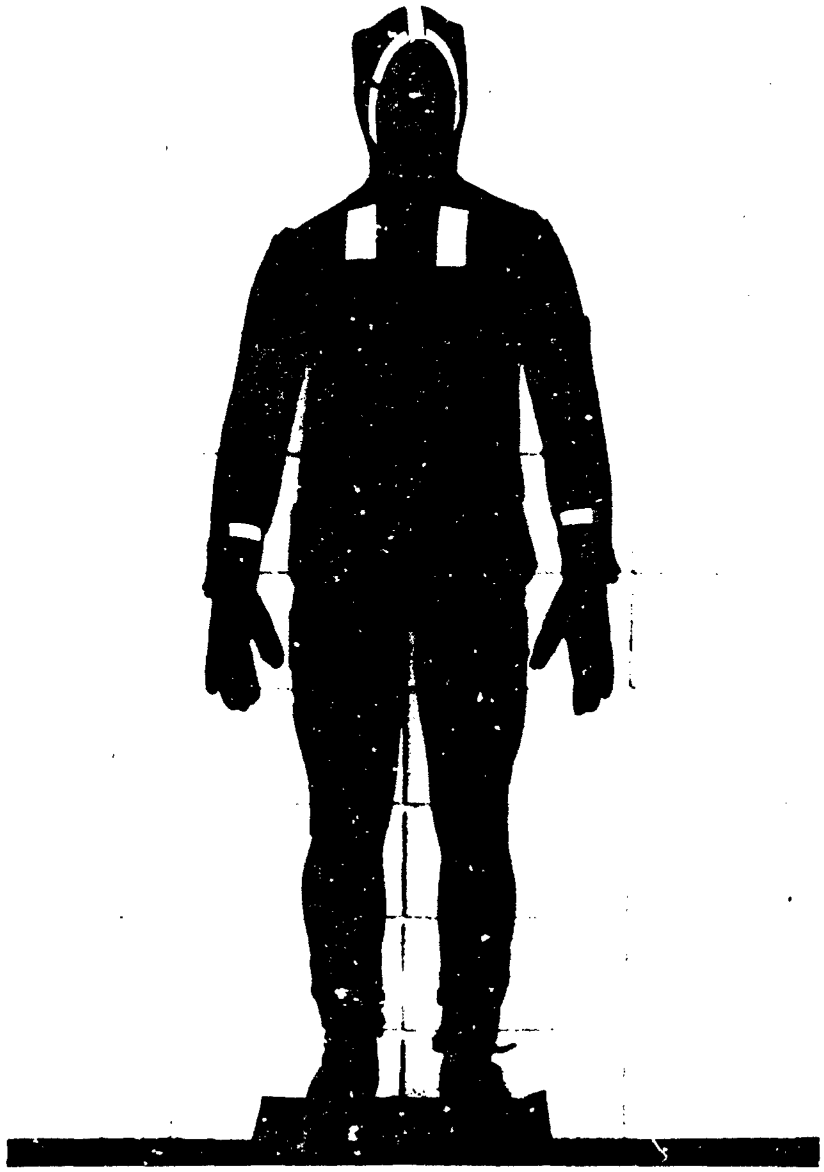

Figure 3. Wet suit (shown without flight gear)

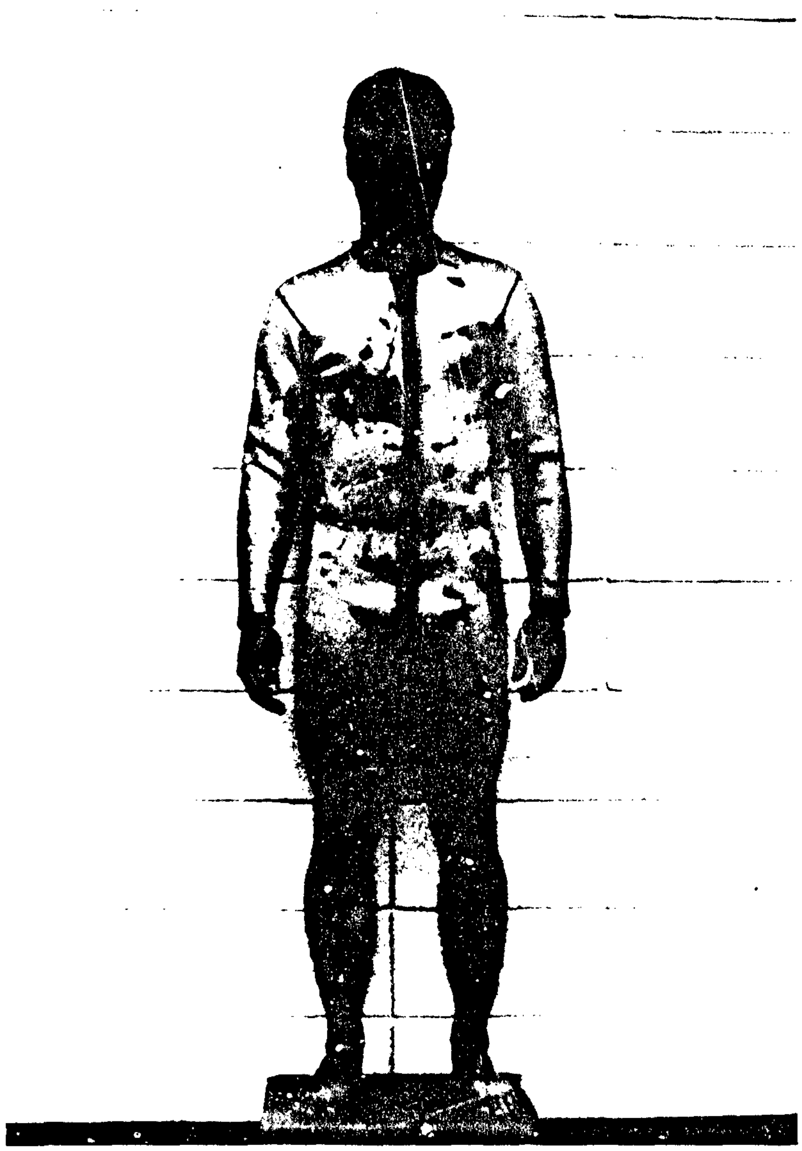

Figure 4. Shorty wet suit

Figure 5. Shorty wet suit worn underneath the flight suit

Figure 6. Aviation coveralls (shown without flight gear)

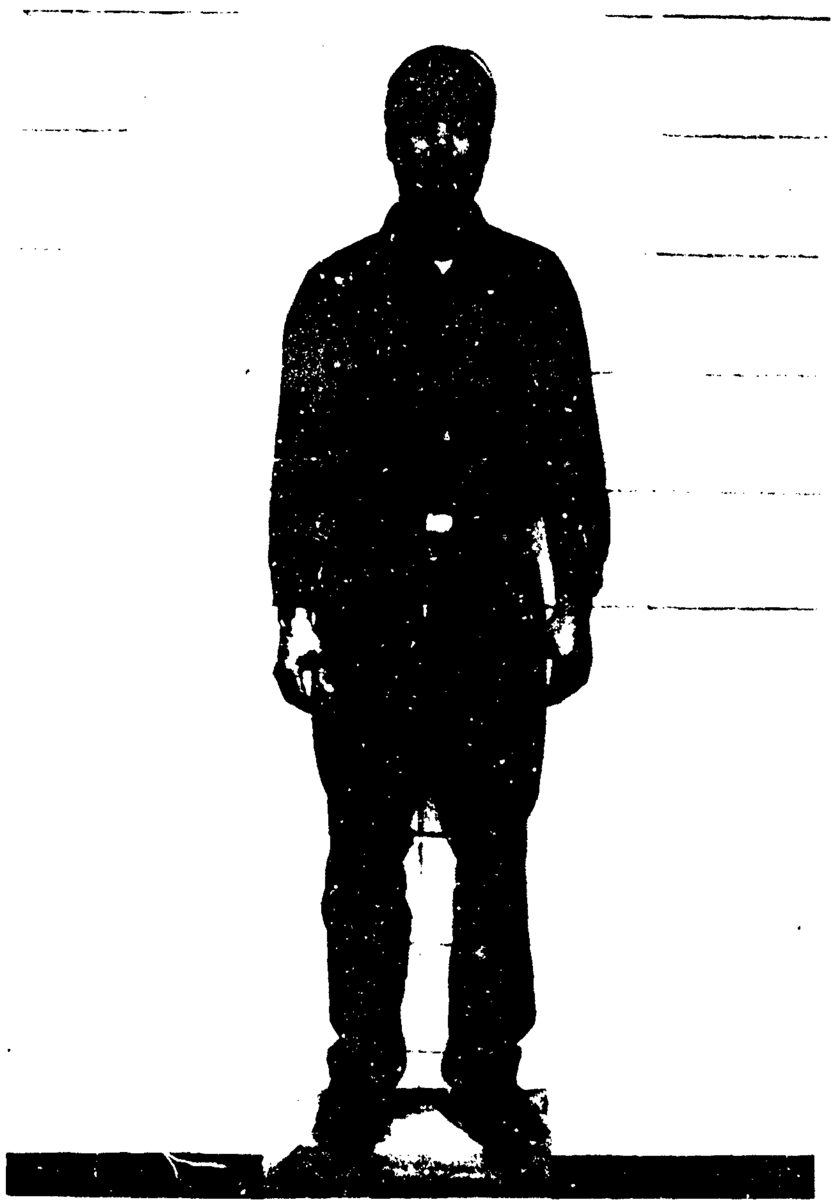

Figure 7. Coast Guard working blue uniform

Figure 8. Boatcrew coveralls

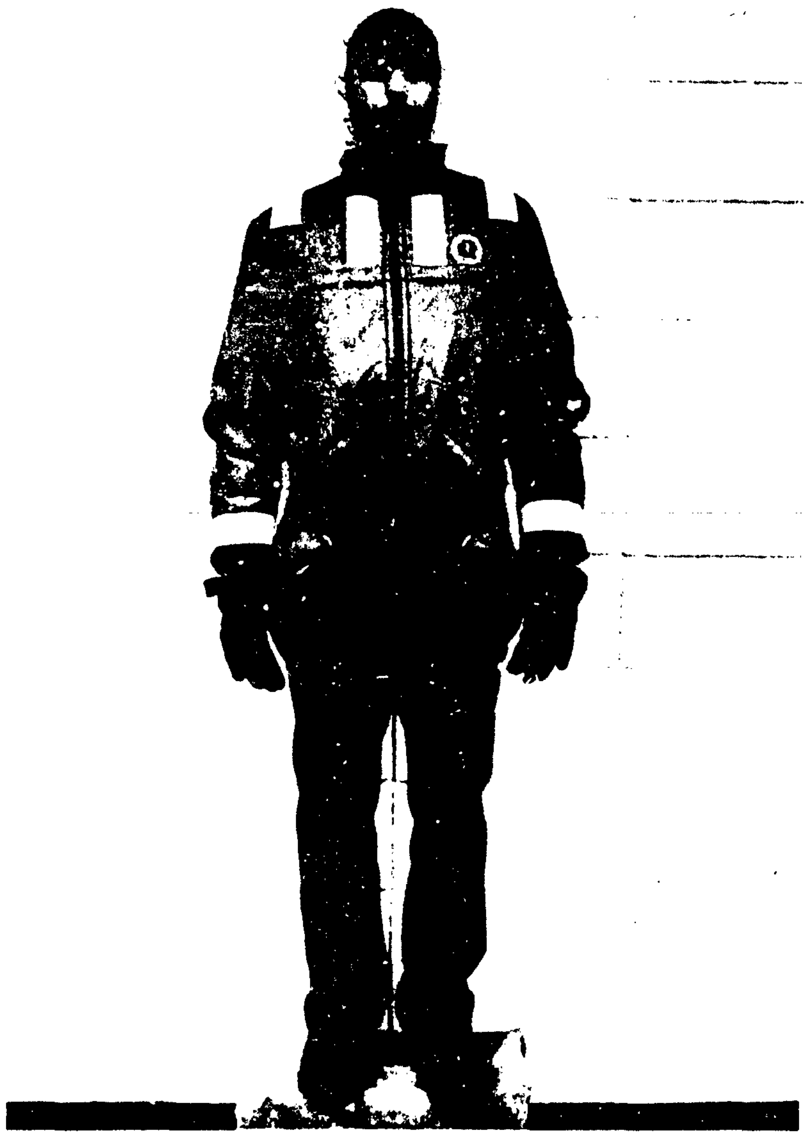

Figure 9. Float coat with beaver-tail deployed

Figure 10. Dry suit

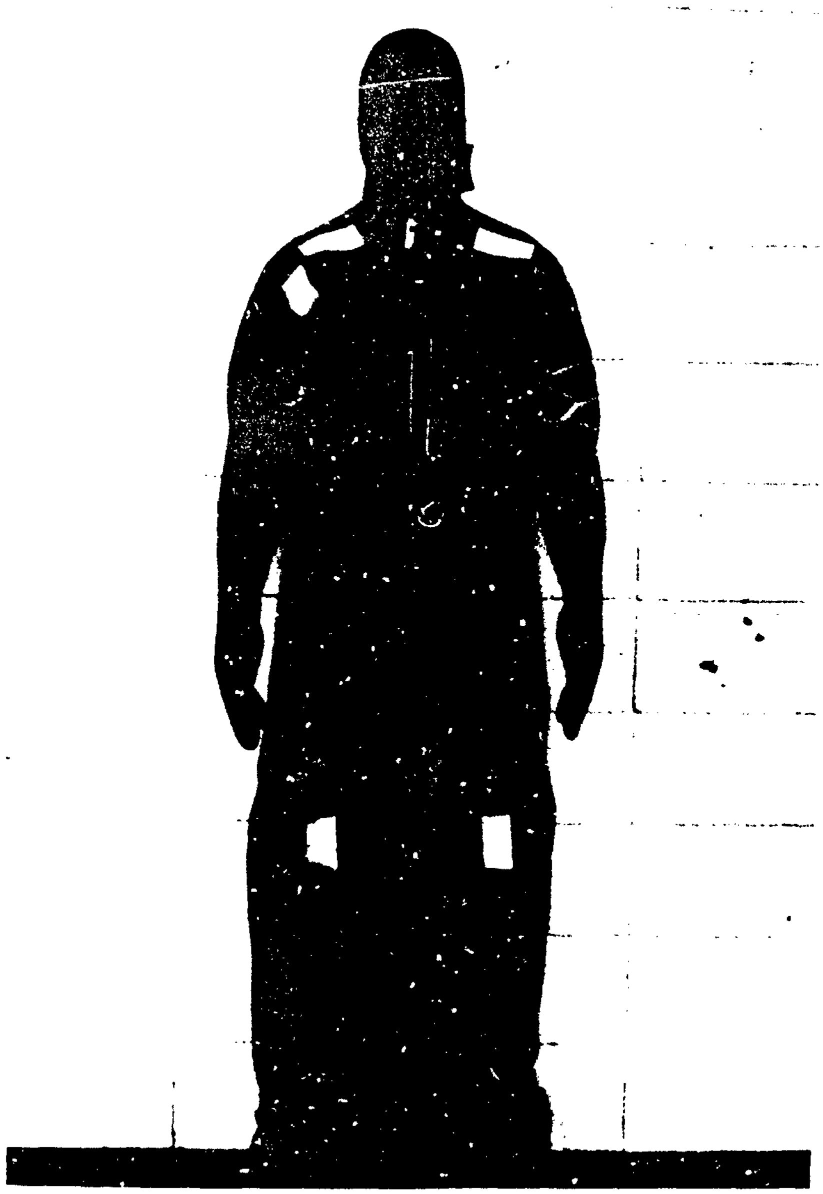

Figure 11. Survival suit

During each immersion test, each garment-ensemble was configured for maximum protection. All zippers were closed; hoods were securely fastened; ankle, wrist and thigh straps were tightened; beaver-tails were deployed, etc.

Other types of protective clothing used by branches of the U.S. or foreign military services were not tested in this study because such clothing is not currently part of the Coast Guard's inventory.

Tabl. 3 lists the total buoyancy provided by each of the garment-ensembles during the immersion tests. Buoyancy was calculated by immersing each item in water for two hours (to facilitate release of trapped air) and then measuring the amount of added weight required to achieve neutral buoyancy (19).

TABLE 3. BUOYANCY OF ANTI-EXPOSURE GARMENT-ENSEMBLES

Garment	Garment Buoyancy (kg)	Additional Buoyancy (kg)	Additional Weight (kg)(a)	Total Ensemble Buoyancy (kg)(b)
Flight Suit	0	14.5(c)	2.2	12.3
Wet Suit	7.8	14.5(c)	2.2	20.1
Shorty Wet Suit	2.9	14.5(c)	2.2	15.2
Aviation Coveralls	7.1	14.5(c)	2.2	19.4
Boatcrew Coveralls	11.0	5.4(d)	0.7	15.7
Float Coat	7.3	-	0.7	6.6
Dry Suit	10.0	(e)	-	10.0+
Survival Suit	10.5	@15(f)+(e)	0.7	@25.5+

(a) Flight helmet (1.5 kg) and/or flight boots (0.7 kg when submerged)
(b) (Garment buoyancy) + (Additional buoyancy) - (Additional weight)
(c) Inflatable life-vest (LPU-25/P)
(d) Inflatable pillow attached at shoulders
(e) Variable amount of trapped air between suit and subject
(f) Inflatable tube around chest

D. Measurements

Rectal temperatures were measured with a Yellow Springs Instruments (YSI) reuseable thermistor (YSI Model 401) inserted 12 cm from the anus. A 2 cm length of rubber tubing was situated 10 cm from the thermistor tip so that following insertion the tubing lay just within the internal anal sphincter. The tubing

thus prevented accidental displacement of the probe. The thermistor was specially modified by YSI to consist of a 6-inch length of vinyl-shielded cable lead connected to 6 feet of ribbon cable lead (YSI Model 409) terminating in a female, waterproof connector. The model designation for these modifications was YSI S-18268. Rectal temperatures were recorded on a digital telethermometer (YSI Model 49TA) attached to a 12-channel switchbox (YSI Model 4002).

Groin skin temperatures were obtained from a site directly over the femoral vessels, two inches inferior to the inguinal ligament. This region had previously been shown by Hayward et al. to be an area of high heat loss during immersion hypothermia (20). Back skin temperatures were obtained from a site two-inches lateral to midline and one-inch inferior to the right inferior scapular angle. Decreased skin temperatures at this site had previously been shown by Hayward et al. to correlate well with rectal temperature cooling rates (1).

Skin temperatures were measured with YSI reuseable surface temperature thermistors (Model 409B) modified to terminate in female, waterproof connectors. The model designation for this modification was YSI S-18334. The skin thermistors were attached with waterproof adhesive tape following isopropyl alcohol cleansing of the site. Skin tempertures were recorded on a continuous, direct-reading telethermometer (YSI Model 46TUC) attached to a 12-channel switchbox (YSI Model 4002).

The female waterprooof connectors from the rectal and skin temperature leads were fitted onto male waterproof connectors attached to 100-foot vinyl-shielded cable leads. These terminated in standard YSI 400 series right-angle molded phone plugs, which were inserted into 12-channel switchboxes. Model designation for the 100-foot connector cables was YSI S-18335/100.

Heart rates were measured with adhesive disc electrocardiograph (ECG) electrodes attached to the left shoulder, and to the left and right anterior chest. The skin sites in each location were cleansed with isopropyl alcohol prior to electrode placement. Leads from the electrodes were bundled into a 6-foot length of vinyl-covered waterproof cable, terminating in a locally constructed waterproof female connector. The male connectors for the ECG leads consisted of locally constructed waterproof, rigid, plastic cylindrical floats connected to 75-foot waterproof cables terminating in standard phone plugs. The plastic float served not only as a waterproof junction but also as a buoyant device for preventing the weight of the ECG cables from putting traction on the disc electrodes. Heart rates were recorded from a Tektronix oscilloscope attached to a 6-channel switchbox.

All recording instruments were located in the enclosed wheelhouse of the 52-foot Motor Lifeboat (MLB) TRIUMPH. The wheelhouse provided shelter for the data recorder and protection of the instruments from wind and spray.

Subjective evaluations were obtained after each immersion for cold discomfort, tightness of garment fit and amount of cold-water flushing within each garment-ensemble. Each item was rated on a linear scale from zero (least) to ten (most).

During every immersion, each subject was fitted with a rescue harness attached to 100 feet of 1/2" polypropylene line. The various cables for the temperature and ECG sensors were suspended from the line by shower curtain hooks. This procedure minimized the possibility of entanglement and permitted rapid retrieval of a subject in the event of an emergency.

E. Environmental Conditions

All immersions were performed in the Columbia River near Coast Guard Station Cape Disappointment, WA during a six-week period in April-May, 1984. Calm water tests were performed at the stations's boat docks. Calm water conditions were as follows: 1) water temperature: 10.67 ± 0.17 degrees C.; 2) air temperature: 12.35 ± 1.96 degrees C.; 3) wind speed: 5-10 knots; 4) sea state: no swells, no wind chop, current of 0-2 knots. Figure 12 shows a typical calm water test.

Rough water tests were performed at two different sites: 1) in the Columbia River Bar, a region noted for its heavy seas; or 2) in Baker Bay, using the wake of a 44-foot MLB to create swells and breaking seas and using the wake of a 17-foot rigid hull inflatable boat to create wind chop. The second site was required because of a prolonged period of unusally stable weather which caused abnormally calm sea conditions in the Columbia River Bar. Environmental conditions during the rough water tests were as follows: 1) water temperature: 11.12 ± 0.15 degrees C.; 2) air temperature: 12.42 ± 2.08 degrees C.; 3) wind speed: 10-20 knots; 4) sea state: 4-6 foot swells, 2-3 foot wind chop, occasional 4-foot breaks, 0-3 knots current. Figures 13 and 14 show typical rough water tests.

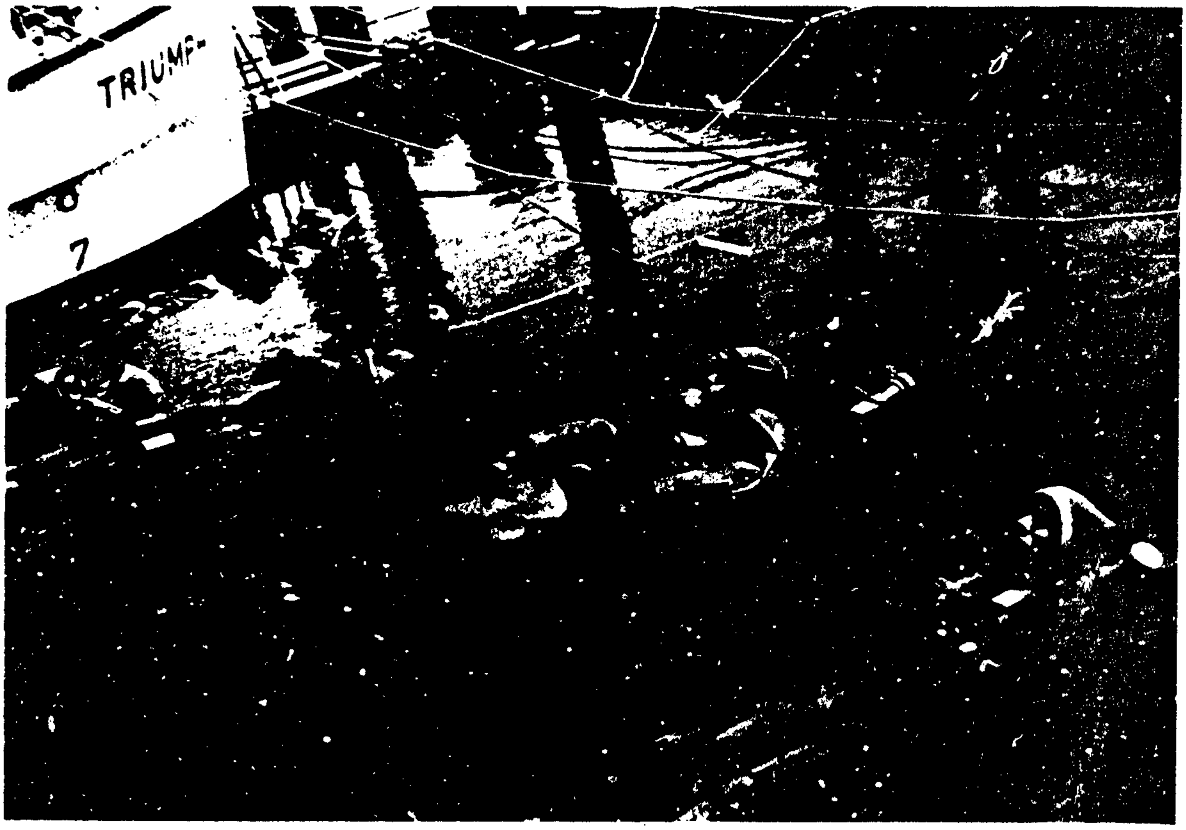

Figure 12. Calm-water test

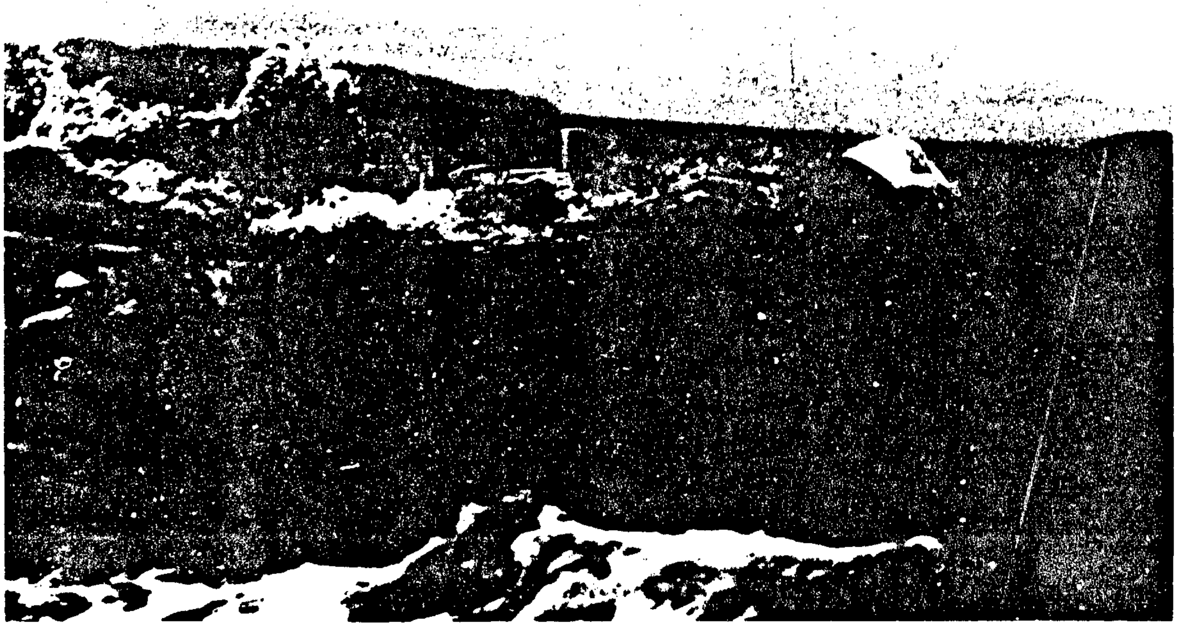

Figure 13. Rough-water test (river bar)

Figure 14. Rough-water test (boat wake)

F. Procedures

Approximately one hour prior to each immersion, the subjects were instrumented with the rectal, skin and ECG sensors. The appropriate garment ensembles were then loosely-donned and excess physical activity was avoided to prevent overheating. The subjects were then transported to the boat docks of Station Cape Disappointment to either prepare for calm water immersion or to get underway aboard TRIUMPH in preparation for rough water immersion.

For calm water tests, the garment ensembles were configured for testing (e.g. life-jackets were donned; all zippers were closed; all wrist, ankle and thigh straps were tightened; hoods were donned; etc.), and the waterproof connections on all instrument cables were fastened. Ten minutes prior to immersion, baseline rectal temperatures, skin temperatures and heart rates were recorded. These were repeated at five minute intervals until immersion at time t=0.

At time t=0 the subjects entered the water. Measurements of temperatures and heart rates were recorded every five minutes until emersion. During calm water tests the subjects remained as motionless as possible. A subjects's immersion was terminated when any one of the following end-points was reached: 1) rectal temperature of 35 degrees C.; 2) ninety minutes elapsed time; 3) subject request for emersion; 4) medical officer direction for emersion. Once out of the water a subject was disconnected from the sensor cables and immediately transported to the rewarming site. There he was assisted in removing the garment-ensemble and sensors. Subjects were then rewarmed in two-stages: 1) five to ten minutes of rewarming in a sauna at 65 degrees C.; 2) 20-30 minutes of rewarming in a circulating hot-water bath at 38 degrees C. Following rewarming, the written subjective evaluations of garment-ensemble performance were completed.

For rough-water tests, the subjects were tansported aboard TRIUMPH to the testing site. During the transit period both excess activity and exposure to cold wind were prevented in order to minimize over-heating or premature cooling, respectively. When appropriate rough water conditions were located, TRIUMPH was anchored and the subjects were prepared for immersion. Garment-ensembles were configured for testing and ten minutes of baseline data were recorded, as described above. At time t=0 the subjects entered the water and were positioned approximately fifty feet aft of TRIUMPH's stern. During all rough water tests the subjects were required to perform almost continuous compensatory movements to maintain their stability and airway freeboard in the waves and wind chop of the rough seas. This level of activity, although less than that of swimming, was

sufficient to prevent the subjects from remaining motionless as they did in the calm-water tests.

The following safety procedures were used during all rough water tests: 1) every subject was fitted with a harness whose retrieval line was attached to TRIUMPH; 2) every garment-ensemble had bouyancy ranging from 6.6 to 25+ kg; 3) a 17-foot Avon rigid hull inflatable rescue boat, manned by an experienced coxswain and at least one rescue crewman, was positioned directly in front of the subjects; 4) one medical officer was stationed either in the rescue boat or in the water with the subjects.

Rough-water immersions were terminated under the same conditions as for calm water tests. Following emersion, subjects were either transported to a nearby beach by the rigid hull inflatable rescue boat for subsequent transport by vehicle to the rewarming site, or they were transported by a 30-foot Surf Rescue Boat to the boat docks for subsequent transport by vehicle to the rewarming site. Transport times following rough water emersions were 5-10 minutes. Procedures at the rewarming site were identical to those described above for the calm water tests.

G. Statistical Analysis

Statistical analyses of garment-ensemble performance were based on units of variation derived from relevant segments of the data profiles of rectal and skin temperatures across time and of heart rates across time. For each combination of subject, garment-ensemble and water condition, these units of variation defined four dependent variables: 1) individual rectal temperature cooling rate; 2) individual back skin temperature change; 3) individual groin skin temperature change; and 4) individual heart rate. Individual rectal temperature cooling rates were estimated from least squares linear regression of segments of the rectal temperature curves. For the six "wet" garment-ensembles, a linear segment of the cooling curve was established by 15 minutes of immersion and persisted until emersion. For the two "dry" garment-ensembles, a linear segment of the cooling curve was established in most cases by 45 minutes of immersion and persisted until emersion. Slope estimates for "wet" and "dry" garments were therefore derived respectively from the 15 minute-to-emersion and 45 minute-to-emersion segments of the rectal temperature curves. The resulting cooling rate estimates were associated with extremely high correlation coefficients in almost all cases.

Individual groin and back skin temperature changes were each estimated from the difference between a subject's mean pre-immersion skin temperatures and a mean of skin temperatures from the corresponding 15-30 minute segment of the curve. The 15-30 minute segment was selected for reasons of physiological relevance and comparability of data among subjects. The greatest proportion of the skin temperature decline for any particular subject usually occurred by 15 minutes of immersion, and all subjects had immersion times of at least 30 minutes. Individual mean heart rate estimates were computed from 15-30 minutes of immersion for similar reasons of data comparability among subjects.

Statistical comparisons of garment-ensemble performance between calm and rough seas were carried out as a series of paired t-tests for the four dependent variables, with sample pairs consisting of data from each subject's calm and rough water immersions for a particular garment-ensemble. Statistical comparisons of the garment-ensembles within each water condition were carried out in the context of a univariate repeated measures model with garment type considered as a single within-subjects factor for each of the four dependent variables. For rectal temperature cooling rates and for groin and back skin temperature changes, the pooled error estimates used in the overall F-tests for equality of garment means were also used in Tukey's (all possible) pairwise mean comparisons procedure (21) to obtain homogeneous groupings of the garments in each water condition. When necessary, missing values were estimated using standard methods (22) in order to obtain the repeated measures pooled error estimates. A logarithmic (ln) transformation of rectal temperature cooling rates was performed prior to the repeated measures analyses because this unit of variation was found to have a positive linear dependency of the garment means on corresponding standard deviations. Because of the presence of several extremely small, positive, individual cooling rates, the specific transformation had the form ln(absolute(rate-1)).

The results of the above anaylses were interpreted very conservatively because of possible inhomogeneity of variance (heteroscedasticity) and possible lack of compound symmetry in the variance-covariance matrix for several of the repeated measures models. Specifically, the Huynh-Feldt adjustment for degrees of freedom was employed in both the overall F-tests and Tukey's multiple comparison procedure to compensate for possible violations of the variance-covariance assumptions (23). The statistical significance of the homogeneous groups and their overlap, as indicated by Tukey's procedure, were consequently considered in terms of overall trends rather than in terms of the specific location of individual garment means.

In addition to water condition and garment type, other covariates considered in the statistical analysis were: 1) pre-immersion rectal and skin temperatures; 2) time of day for each immersion; 3) water temperature; 4) day number of each immersion over the course of the study; and 5) whether or not boatwake was used in generating water conditions for each of the rough-water immersions. Initial evaluation of these variables was based on graphic display, magnitude and variability. Because of the possibility of subject acclimatization to cold over the course of the study, and because of the potential difference in the physical nature of rough seas encountered naturally and those produced artificially by boatwake, both the significance of day number of immersion as a continuous covariate for rectal temperature cooling rates in calm and rough water and the significance of boatwake as a 0-1 covariate for rough-water rectal temperature cooling rates and for rough-water groin and back skin temperatures were considered in the corresponding repeated measures models for intergarment comparisons.

The relationships between rectal temperature cooling rates and skin temperature changes across the eight garment-ensembles for each subject in each water condition were evaluated with the simple correlation coefficient (R). Correlation coefficients were also used to describe the relationships among various mean subjective assessments of the garment-ensembles and mean garment rectal temperature cooling rates. P-values associated with R refer to the hypothesis of statistical difference from zero.

Individual survival times were estimated from extrapolations of rectal temperature cooling rates and were used to estimate mean survival times (expressed as 95% confidence intervals) for each garment-ensemble in each water condition. Several instances of highly physiologically unreasonable individual survival time estimates resulted from the requirement to extrapolate over periods of time far outside the range of data on which the cooling rates were based. These few unreasonable estimates were all associated with one particular subject or with several instances of cooling rates which were extremely close to zero. Such highly extreme individual survival times were subsequently excluded from the confidence interval computations in order to provide meaningful estimates of mean survival time over the extrapolated range of temperatures.

RESULTS

Rectal Temperature Changes

The various garment-ensembles described on pages 5-7 and listed in Table 2 will subsequently be referred to simply as wet suit, flight suit, etc. Data presented and discussed for each garment, however, pertain to the entire ensemble of clothing and other items worn with the garment and not to the garment alone. Data on the wet suit, for example, refer to subjects wearing not only the wet suit itself but also cotton underwear, an inflatable life-vest, a flight helmet, flight boots, etc.

Figures 15 and 16 show the composite rectal temperature cooling curves for subject 2 for the eight garment-ensembles in calm water and rough water, respectively. These figures demonstrate the different cooling rates obtained in each sea condition for the various garment-ensembles. The data of subject 2 are shown in detail because his responses most closely matched the average response of the eight subjects. Figure 17 shows a comparison of calm vs rough-water cooling curves for each of the eight subjects in each of the eight garment-ensembles. The horizontal rows in Figure 17 demonstrate the variation in cooling rates among garment-ensembles for each subject. The vertical columns in Figure 17 demonstrate the variation in cooling rates among subjects for each garment-ensemble. Figures 15-17 together illustrate the typical time course of core temperature changes measured in this study. The cooling curves for all garment-ensembles, except the dry-suit and wet-suit, showed a similar pattern. Only small changes in rectal temperature occurred over the first 10-15 minutes of immersion. This was followed by a linear rate of decline over the remainder of the immersion. This pattern occurred in both calm and rough-sea conditions. The cooling curves for the dry suit and survival suit demonstrated a longer period of temperature stability before linear cooling occurred, especially in calm-water. For these garment-ensembles the initial period of temperature stability in calm-water was slightly longer but was still followed by a linear cooling rate. In rough-water, however, many of the subjects' rectal temperatures actually increased over the first 30 minutes of immersion and then followed a linear rate of decline.

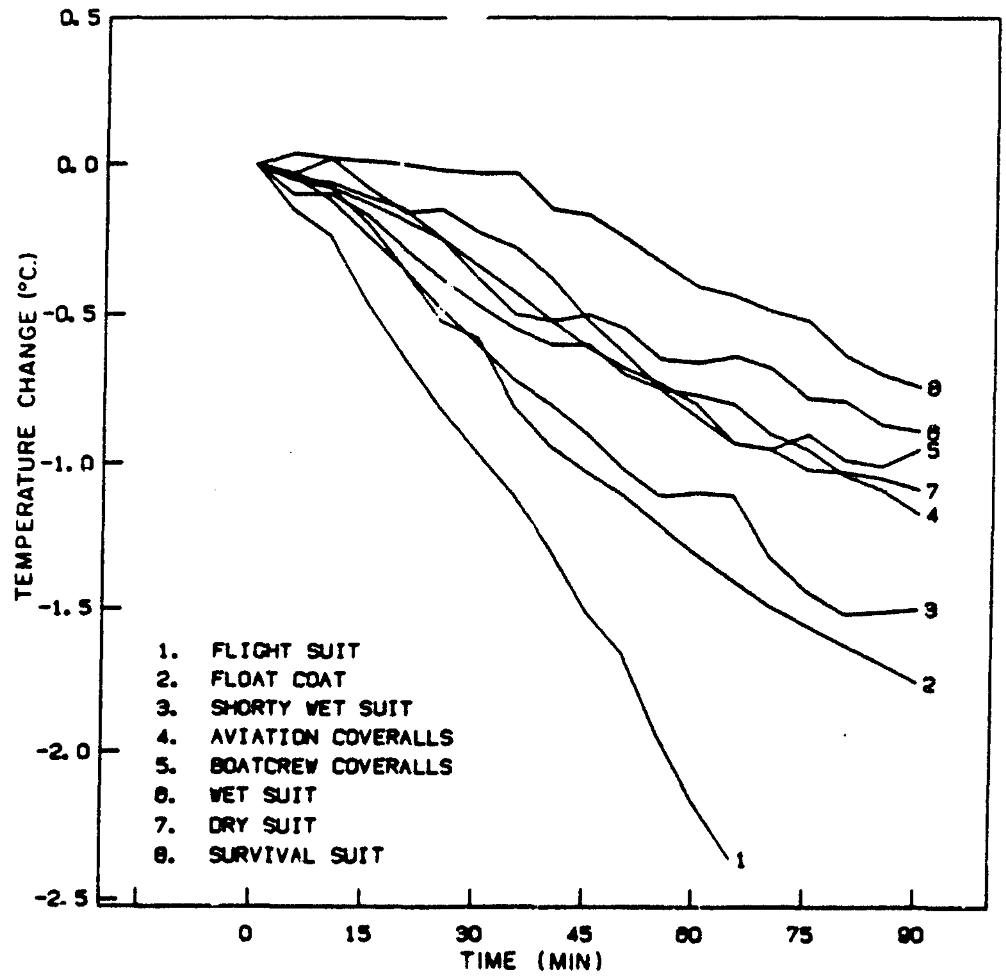

Figure 15.
Rectal temperature changes for subject (2) in calm seas.

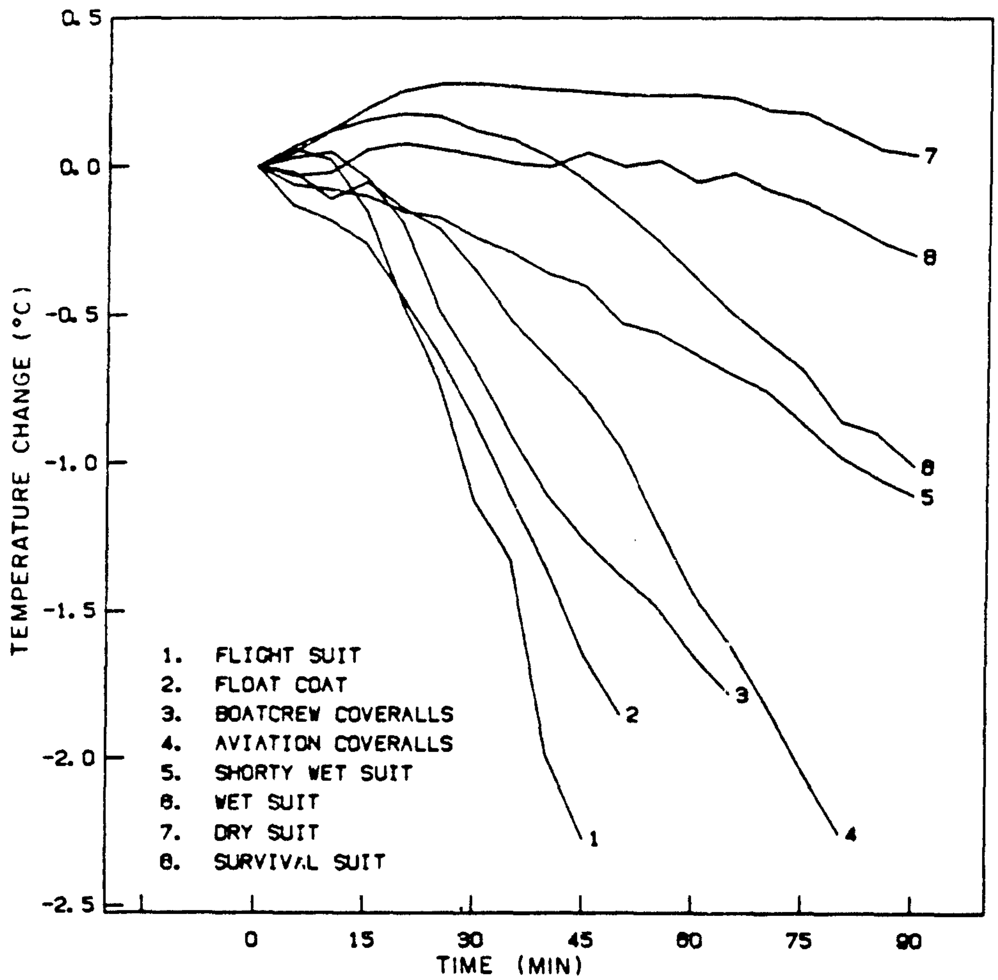

Figure 16.
Rectal temperature changes for subject (2) in rough seas.

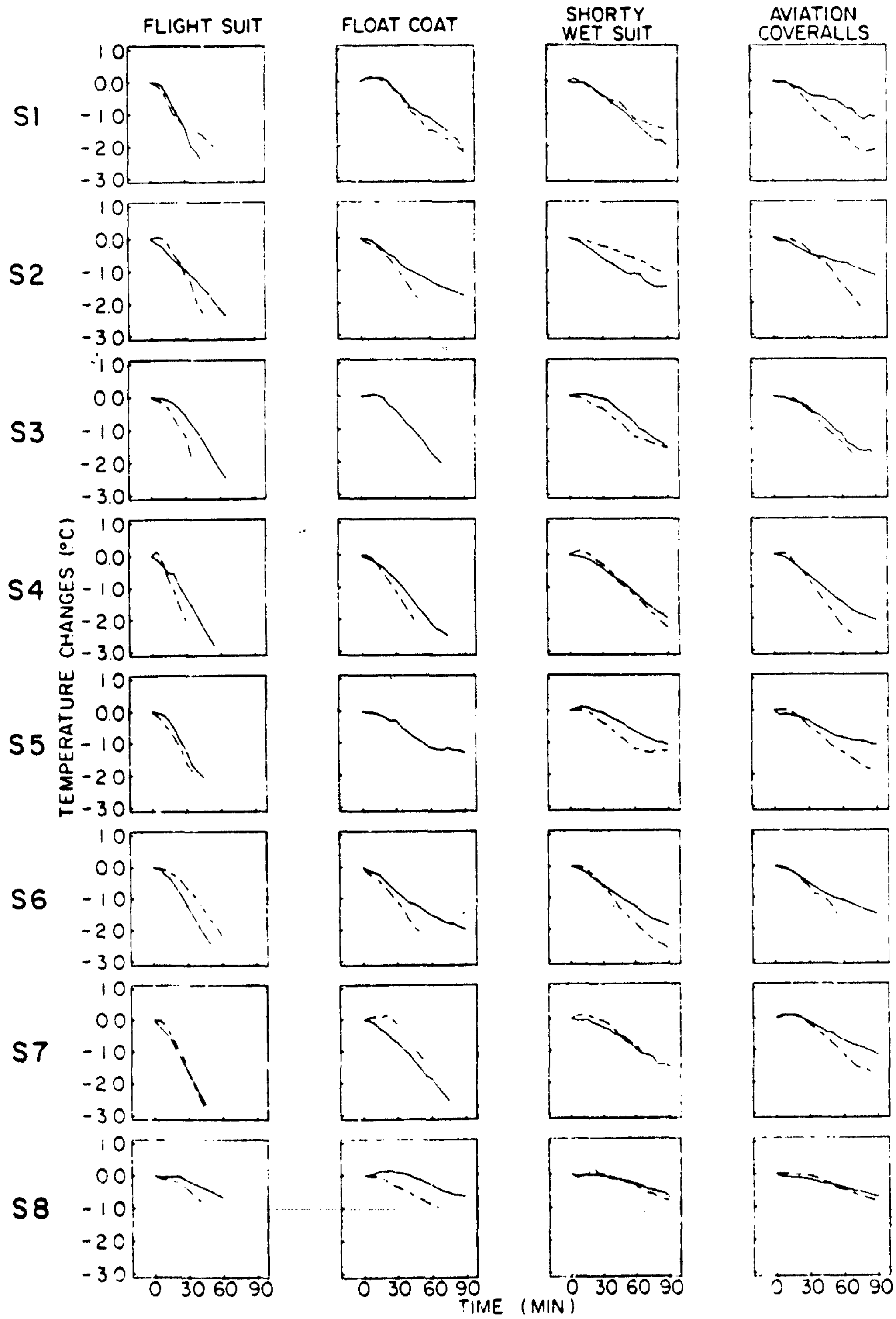

Figure 17.
Rectal temperature changes in calm (——) and rough (- - - -) seas for each subject (rows S1, S2, etc.) in each garment-ensemble (columns).

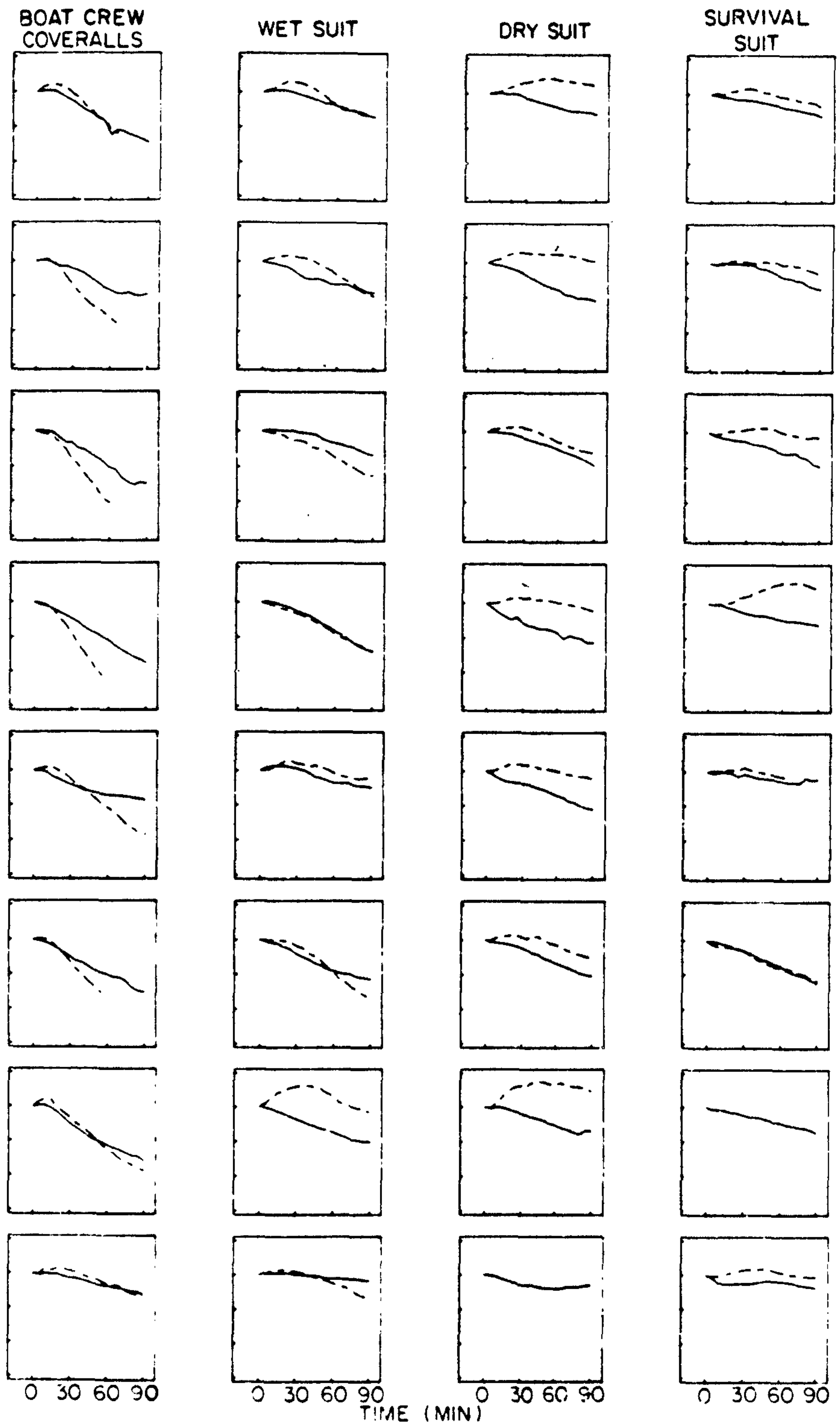

Figure 17.
(cont.)

For the flight suit and the five "wet" garment-ensembles, linear regression analysis of the cooling curves using data from 15 minutes to the end of each immersion showed very high linear correlation ($r > 0.94$) in both calm and rough water. For the two "dry" garment-ensembles, linear regression analysis of the cooling curves using data from 45 minutes to the end of each immersion also showed high linear correlation ($r > 0.82$). These correlations were all significant ($p < 0.05$). Accordingly, cooling rates for subjects in the flight suit and in the five "wet" garment-ensembles were calculated from 15 minutes to end-immersion, and cooling rates for subjects wearing the two "dry" suits were calculated from 45 minutes to end-immersion.

Figure 18 and Table 4 show a comparison of the mean rectal temperature cooling rates for each of the garment-ensembles in the two sea conditions. Subjects wearing the flight suit had the highest mean cooling rates in both calm and rough seas, 3.19 and 3.59 degrees C./hour, respectively, but there was no significant difference between these two values. Subjects wearing the float coat had the next highest cooling rates in both calm and rough seas, 1.61 and 2.40 degrees C./hour, respectively. This 49% increase in cooling rate between calm and rough seas was significant ($p=0.03$). Subjects wearing the shorty wet suit had nearly the same mean cooling rates in both calm and rough seas, 1.22 and 1.33 degrees C./hour, respectively. The small, 9% increase in rough-water over calm-water cooling rate was not statistically significant. The two types of protective coveralls performed almost identically in both calm and rough seas. Subjects wearing the boatcrew coveralls or the aviation coveralls had cooling rates of 0.98 and 1.00 degrees C./hour, respectively. But these cooling rates increased significantly ($p<0.001$) to 1.80 and 1.96 degrees C./hour, respectively, in going from calm to rough-water conditions. Subjects wearing the wet suit had mean cooling rates of 0.66 and 0.91 degrees C./hour, respectively, in calm and rough seas. The 38% increase in mean cooling rate, however, did not quite achieve statistical significance at the $p<0.05$ level ($p=0.055$). The dry suit and the survival suit also performed almost identically to each other in both calm and rough seas. Mean cooling rates in calm water were 0.67 and 0.50 degrees C./hour, respectively. Unlike the increases in cooling rates in rough water observed for the other six garment-ensembles, subjects wearing either the dry suit or the survival suit had lower cooling rates in rough-water, 0.49 and 0.41 degrees C./hour, respectively. The difference was significant for the dry suit ($p=0.026$) but not for the survival suit ($p=0.459$).

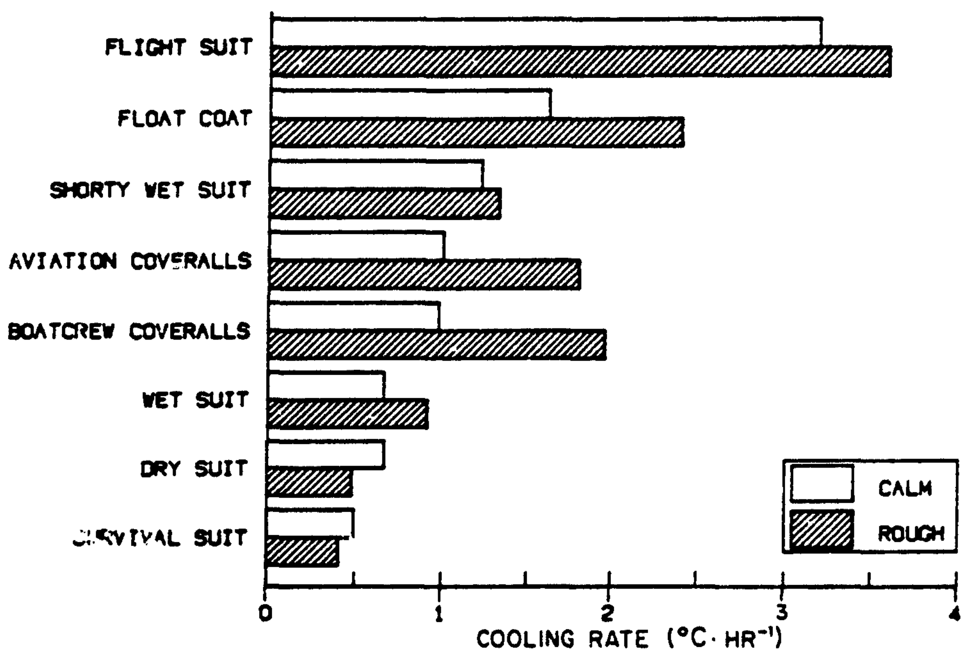

Figure 18.
Mean rectal temperature cooling rates in calm vs rough seas.

TABLE 4. MEAN RECTAL TEMPERATURE COOLING RATES FOR SUBJECTS WEARING ANTI-EXPOSURE GARMENT ENSEMBLES IN CALM AND ROUGH SEAS

Garment	Cooling Rates (°C/hr ± S.D.) Calm	Rough	p*	n**
Flight Suit	3.19 ± 1.11	3.59 ± 1.38	0.462	8
Float Coat	1.61 ± 0.64	2.40 ± 0.77	0.030	6
Shorty Wet Suit	1.22 ± 0.35	1.33 ± 0.47	0.448	8
Aviation Coveralls	1.00 ± 0.37	1.80 ± 0.56	0.001	8
Boatcrew Coveralls	0.98 ± 0.33	1.96 ± 0.69	0.001	8
Wet Suit	0.66 ± 0.27	0.91 ± 0.31	0.055	8
Dry Suit	0.67 ± 0.17	0.49 ± 0.23	0.026	7
Survival Suit	0.50 ± 0.31	0.41 ± 0.21	0.459	7

*p-value from the paired t-statistic for calm vs rough seas comparisons

**n=number of subjects; n<8 indicates missing rough-seas data and subsequent deletion of corresponding calm-seas data for pairwise comparisons.

Figure 19 shows a comparison of mean rectal temperature cooling rates in calm seas for the eight garment-ensembles, arranged in rank order from highest to lowest. The figure also indicates the results of all pairwise comparisons of cooling rates for statistically significant ($p < 0.05$) differences. Subjects wearing the survival suit, the dry suit or the wet suit had the lowest cooling rates, and there were no significant differences in cooling rates among these three garments. Furthermore, in calm-water both the survival suit and the dry suit provided significantly better protection from hypothermia than did any of the other garment-ensembles tested, except for the wet suit. Cooling rates of subjects wearing the wet suit were nearly as small as for the survival suit and dry suit, and they were significantly smaller than cooling rates of subjects wearing the flight suit, float coat or shorty wet suit. However, there were no significant differences in cooling rates between the wet suit and either of the coveralls. Subjects wearing either the boatcrew or aviation coveralls had nearly identical cooling rates which were neither significantly different from each other nor from that of subjects wearing the shorty-wet suit. Cooling rates for subjects in either of the coveralls, however, were significantly lower than that of subjects wearing the float coat or the flight suit. Subjects wearing the shorty wet suit had cooling rates significantly less than those of subjects wearing the flight suit. Subjects wearing the float coat had cooling rates in calm water significantly lower than

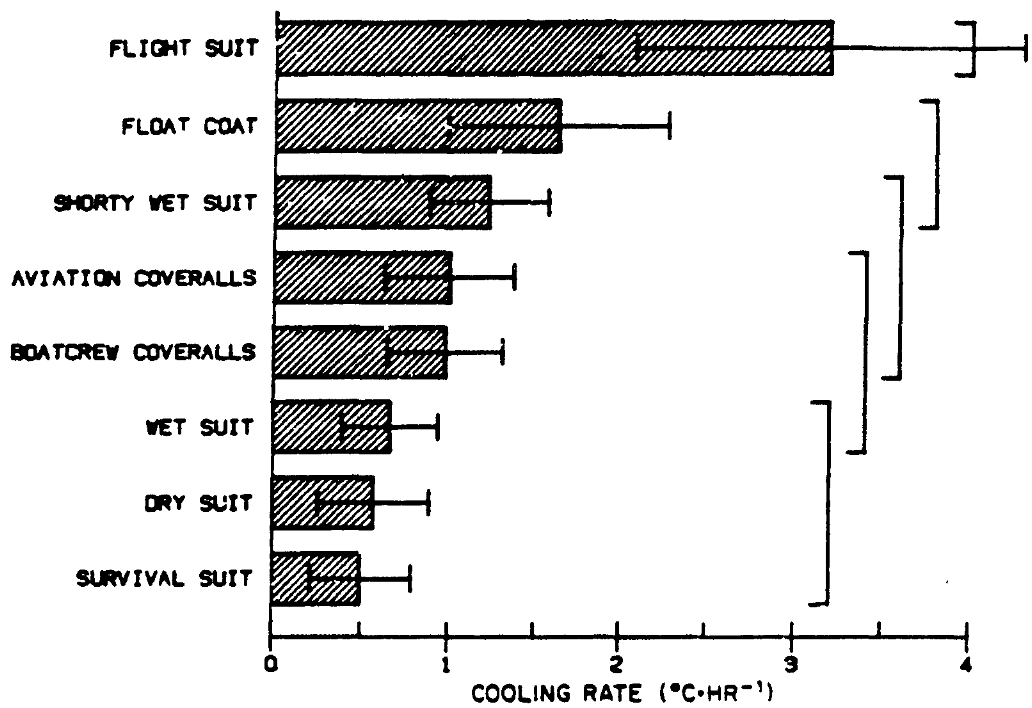

Figure 19.

Intergarment comparison of mean rectal temperature cooling rates in calm seas. Vertical bars indicate groups of garments with statistically similar mean cooling rates (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

those of subjects wearing the flight suit. Subjects wearing the flight suit had significantly higher cooling rates than subjects wearing any of the other garment-ensembles.

Figure 20 shows a comparison of mean rectal temperature cooling rates in rough seas for the eight garment-ensembles, again arranged in rank-order from highest to lowest. It also shows the results of all pairwise comparisons of cooling rates for significant ($p < 0.05$) differences. Subjects wearing either the survival-suit, dry-suit or wet suit again had the smallest cooling rates in rough-water, and there was no significant difference among them. Cooling rates for the survival-suit and dry-suit however, were significantly lower than for subjects wearing any of the other five garment-ensembles. Subjects wearing the wet suit had cooling rates which were not significantly different from those of subjects wearing the shorty wet suit in rough seas. However, the wet suit did produce statistically significantly lower cooling rates among test subjects than did any of the remaining four garment ensembles. The shorty-wet suit improved its relative ranking among the garment-ensembles in rough-sea conditions from that found in calm-water. Subjects wearing the shorty-wet suit had lower cooling rates than did subjects wearing either of the coveralls, the float coat or the flight suit. The primary reason for this change in relative ranking was the significant increase in cooling rates of subjects wearing these other garment-ensembles in rough vs calm-seas combined with the small, non-significant change in cooling rates of subjects wearing the shorty wet suit under these same water conditions. However, significant differences in cooling rates occurred only between the shorty wet suit and the flight suit and between the shorty wet suit and the float coat. Significant differences in cooling rates did not occur between the shorty wet suit and either of the coveralls in rough seas. The boatcrew and aviation coveralls provided similar degrees of protection in rough seas, repeating the findings for these garment-ensembles in calm-water. Both pairs of coveralls provided significantly better protection than did the flight suit, but no significant difference was found between the coveralls and the float coat. Finally, no significant difference was found between cooling rates for subjects wearing the float coat and subjects wearing the flight suit in rough seas. This finding thus differed from that of the calm-water immersions, where the float coat produced significantly lower cooling rates among subjects than did the flight suit.

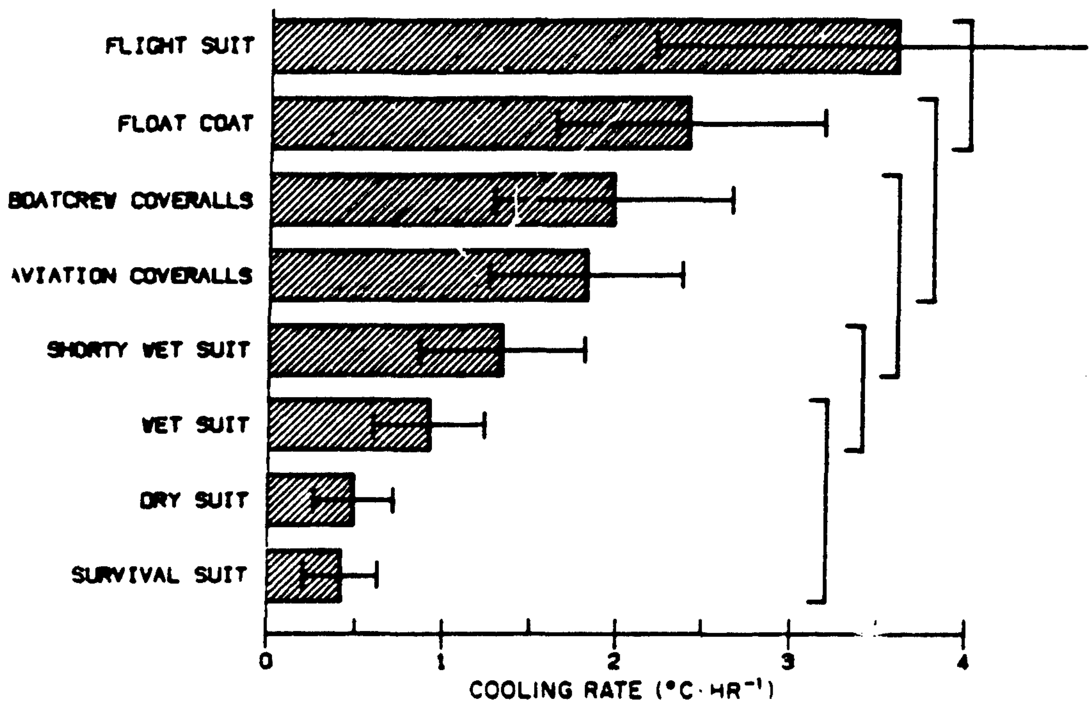

Figure 20.
Intergarment comparison of mean rectal temperature cooling rates in rough seas. Vertical bars indicate groups of garments with statistically similar mean cooling rates (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

Skin Temperature Changes

Figure 21 shows a comparison of calm- vs rough-water groin temperature changes for each of the eight subjects in each of the eight garment-ensembles. Figure 22 shows a similar comparison of back temperature changes. In calm water, both groin and back temperatures showed similar behavior in subjects wearing "wet" garment-ensembles. Since these garments all allowed cold water to come in contact with the skin, groin and back skin temperatures both declined sharply during the first few minutes of immersion. Thereafter, skin temperatures stabilized and fluctuated only slightly. The survival suit and dry suit, however, produced different skin temperature responses in calm water. Since both these garments were "dry", admitting no cold water to contact the skin, both groin and back temperatures showed relatively little decline during the first few minutes of immersion and only small decreases thereafter. In rough seas, skin temperatures among subjects wearing "wet" garment-ensembles again showed steep declines during the first few minutes of immersion. During the remainder of the immersion, however, fluctuations in both groin and back temperatures were frequently greater in rough water than in calm water for these subjects. Figure 23 shows enlargements of selected graphs from Figures 21 and 22 to better illustrate these rough water fluctuations in skin temperatures for subjects wearing "wet" garment-ensembles. In the dry suit and the survival suit, skin temperatues again declined only slightly in rough seas and did not fluctuate widely throughout the immersion.

Figure 24 and Table 5 show comparisons of the mean change in the subjects' groin temperatures between calm- and rough-water conditions for each of the eight garment-ensembles. Subjects wearing the flight suit had the largest mean decline in groin temperatures in calm water, with a drop of 17.1 degrees C. In rough seas, the mean decline in groin temperature was even greater, 18.4 degrees C, and the difference between rough and calm seas was significant. Subjects wearing the float coat showed a mean decline in groin temperature in calm water of 16.0 degrees C. and a significantly larger decline of 19.3 degrees C. in rough water. Subjects wearing the aviation or boatcrew coveralls had mean groin temperature declines in calm seas of 13.8 and 12.7 degrees C., respectively. These increased to 16.2 and 17.4 degrees C., respectively, in rough seas. The differences were significant. Subjects wearing the shorty wet suit showed mean groin temperature declines in calm and rough water of 10.0 and 11.4 degrees C., respectively, but the difference was not significant. Subjects wearing the wet suit had mean groin temperature decreases of 6.9 and 11.3 degrees C. in calm and rough water, respectively. The difference was

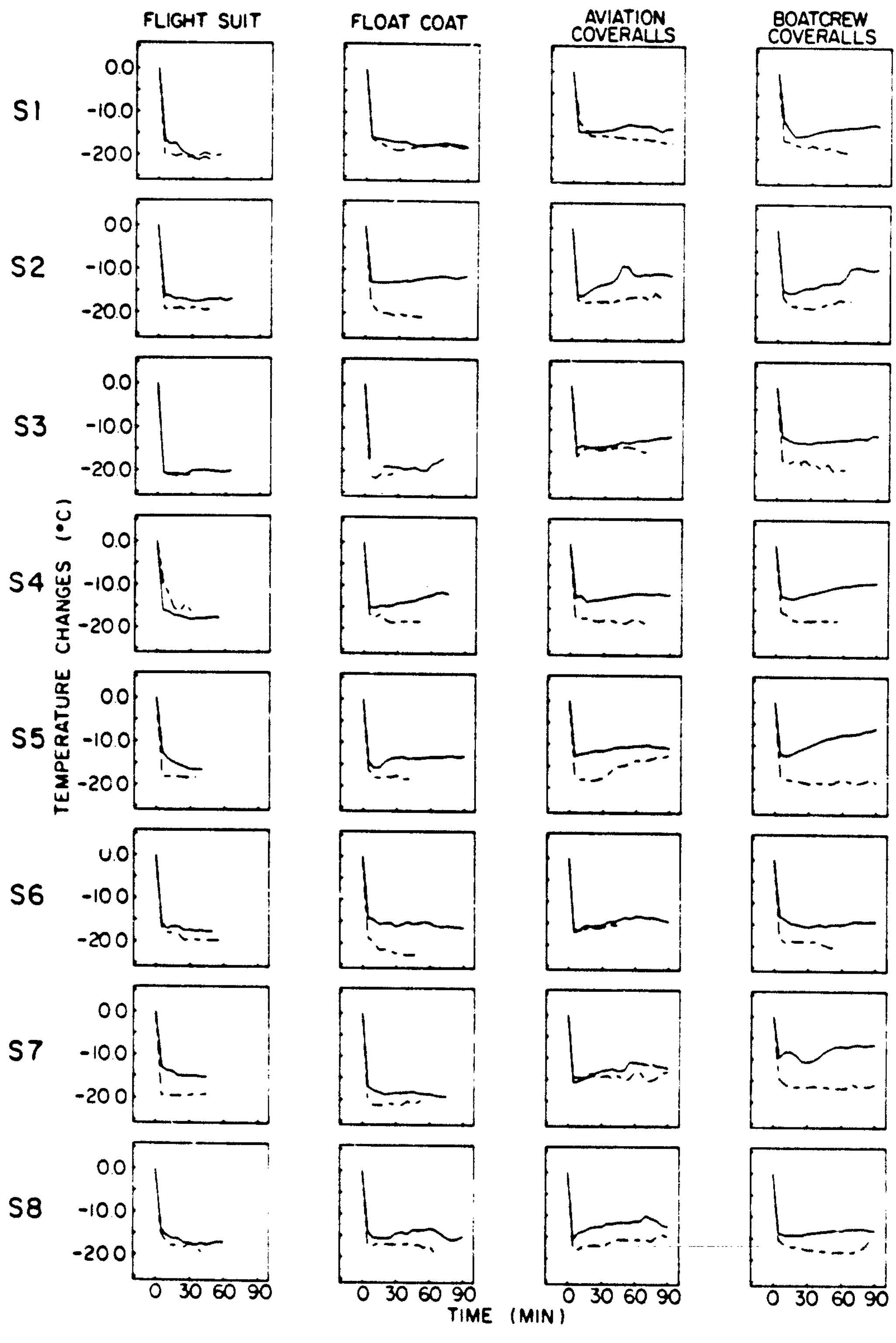

Figure 21.
Groin skin temperature changes in calm (——) and rough (- - - -) seas for each subject (rows S1, S2, etc.) in each garment-ensemble (columns).

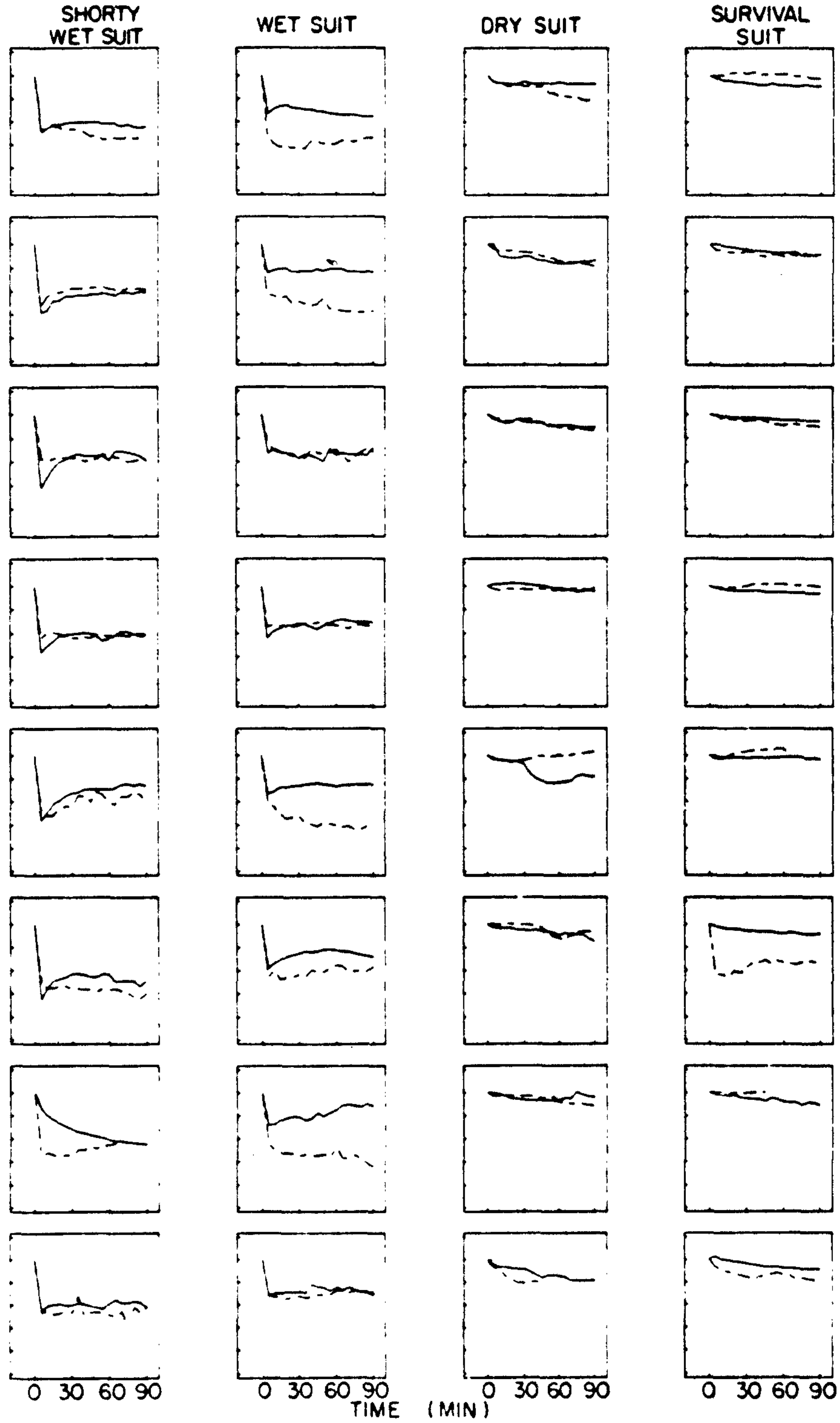

Figure 21.
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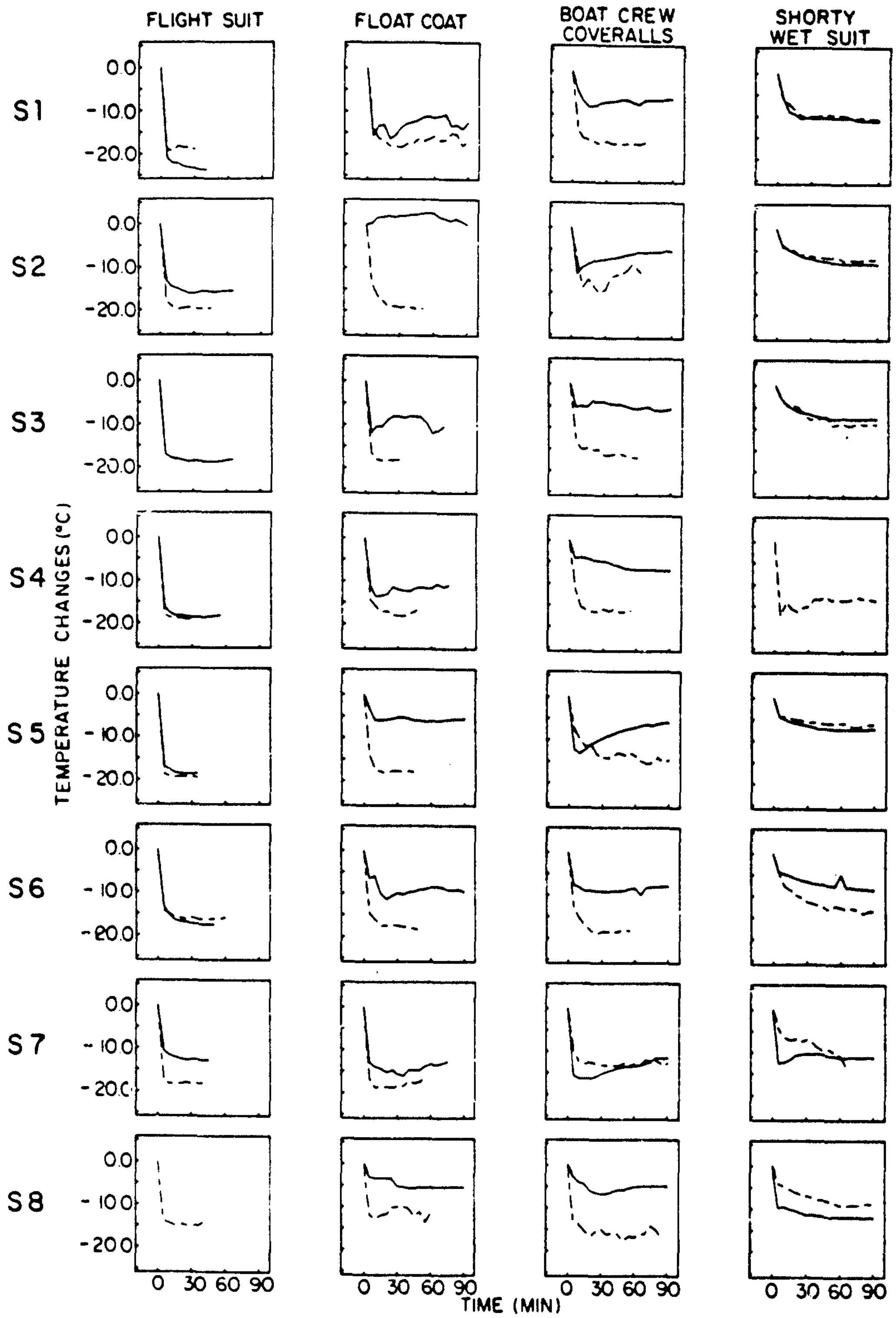

Figure 22.

Back skin temperature changes in calm (——) and rough (- - - -) seas for each subject (rows S1, S2, etc.) in each garment-ensemble (columns).

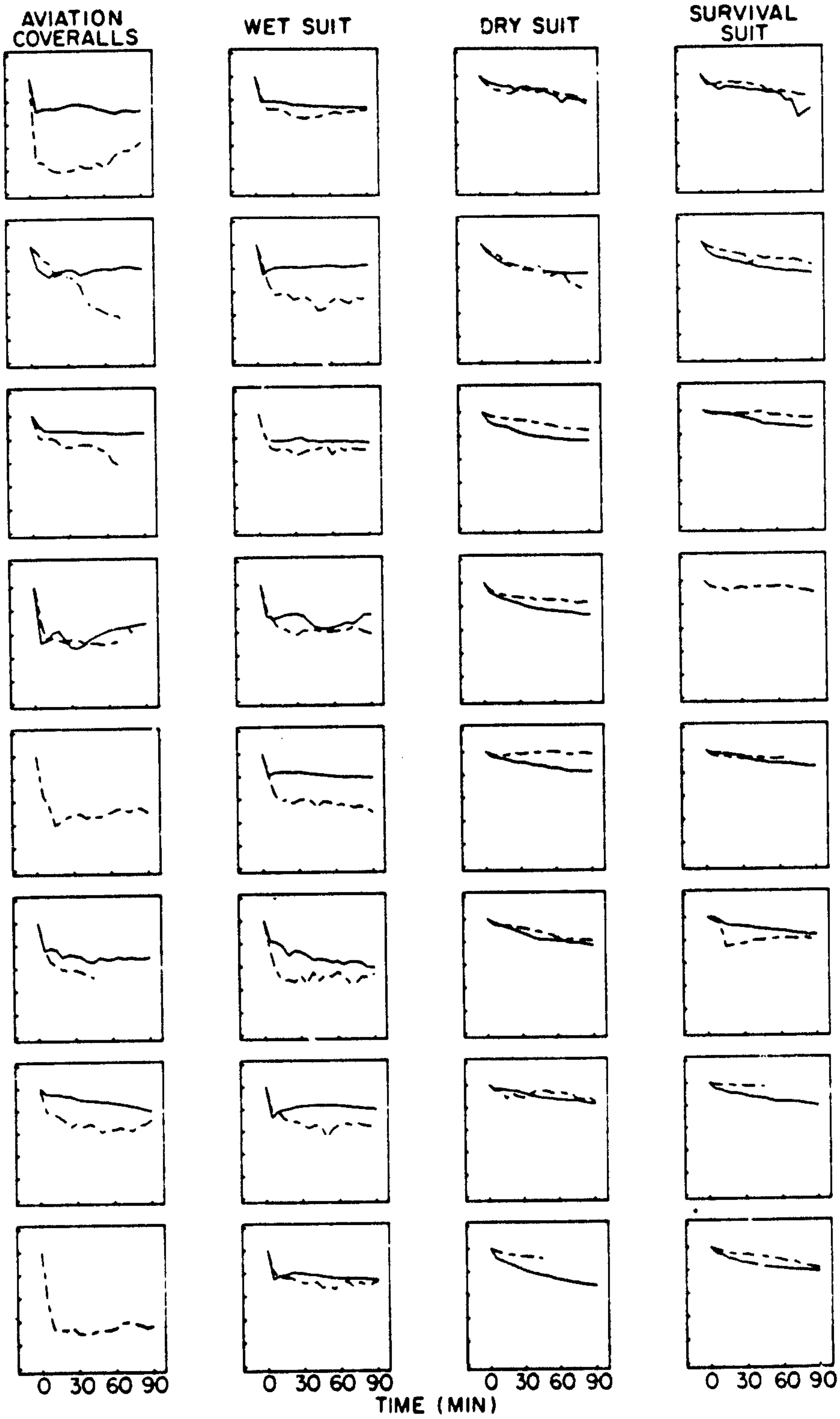

Figure 22.
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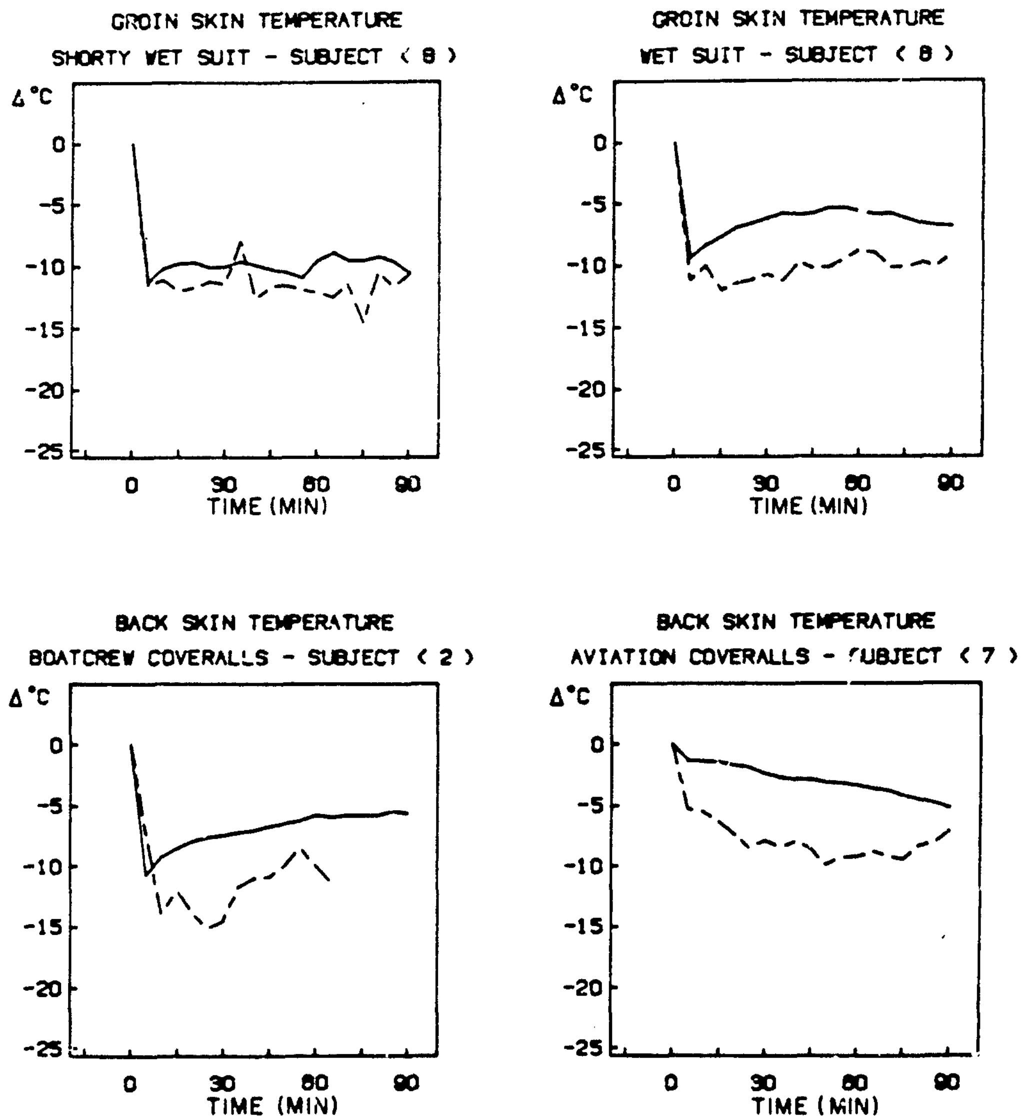

Figure 23.
Skin temperature changes for selected garments and selected subjects in calm (——) vs rough (----) seas.

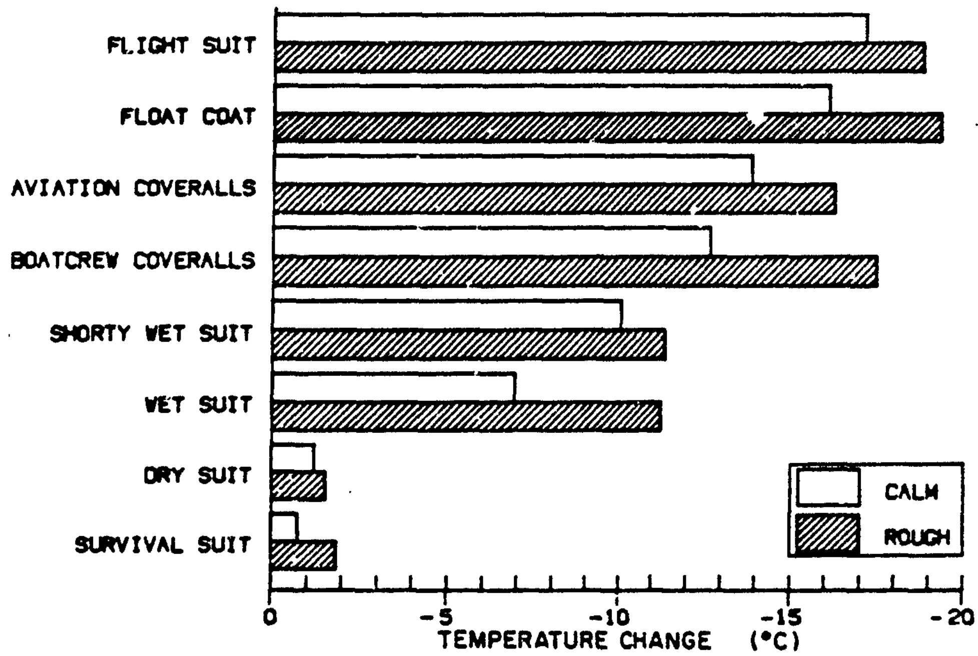

Figure 24.
Mean decline in groin skin temperature in calm vs rough seas.

significant. Subjects wearing either the dry suit or the survival suit had the smallest declines in groin temperatures in calm water, 1.2 and 0.7 degrees C., respectively. These increased only slightly to 1.5 and 1.9 degrees C., respectively, in rough water. The differences were not significant.

TABLE 5. MEAN DECLINE IN GROIN SKIN TEMPERATURE FOR SUBJECTS WEARING ANTI-EXPOSURE GARMENT-ENSEMBLES IN CALM VS ROUGH SEAS

	Groin Temperature Decline (°C. + S.D.)			
Garment	Calm	Rough	p*	n**
Flight Suit	17.10 ± 1.29	18.78 ± 1.48	0.040	8
Float Coat	16.05 ± 1.77	19.30 ± 1.85	0.001	8
Aviation Coveralls	13.86 ± 0.98	16.22 ± 1.53	0.017	8
Boatcrew Coveralls	12.66 ± 1.91	17.43 ± 0.70	0.001	8
Shorty Wet Suit	10.05 ± 1.79	11.36 ± 1.68	0.244	8
Wet Suit	6.92 ± 1.18	11.26 ± 2.72	0.011	8
Dry Suit	1.21 ± 1.05	1.54 ± 1.59	0.519	8
Survival Suit	0.75 ± 0.34	1.86 ± 3.60	0.405	8

*p-value from the paired t-statistic for calm vs rough seas comparisons

**n=number of subjects

Figure 25 and Table 6 show comparisons of the mean change in the subjects' back skin temperatures for each of the garment-ensembles in calm vs rough-water conditions. The flight suit again produced the largest mean decreases in temperatures in both calm and rough seas, 17.5 and 18.4 degrees C, respectively. The difference was not significant. Subjects wearing the float coat, boatcrew coveralls or shorty wet suit had nearly identical decreases in back temperature in calm water, with means of 8.7, 8.5 and 8.4 degrees C., respectively. In rough water, however, the subjects' back temperatures in the float coat and boatcrew coveralls decreased by 17.1 and 15.1 degrees C., respectively. These differences were significant. In contrast, subjects wearing the shorty wet suit in rough seas had a smaller mean decline in back temperature, (7.3 degrees C) than they did in calm seas. The difference, however, was not significant. Subjects wearing either the aviation coveralls or wet suit also had similar mean decreases in back temperature in calm water, 5.8 and 5.4 degrees C, respectively. In rough water, mean back

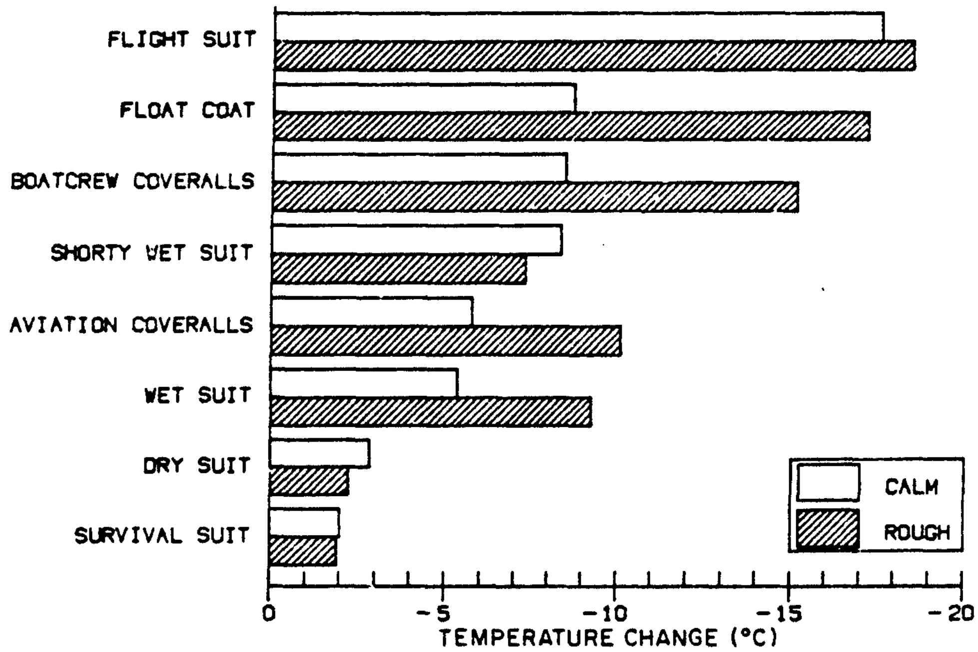

Figure 25.
Mean decline in back skin temperature in calm vs rough seas.

temperatures in these two ensembles decreased 10.1 and 9.3 degrees C, respectively, but only for the wet suit was the difference significant. Finally, subjects wearing either the dry suit or survival suit again had the smallest mean declines in back skin temperatures, 2.8 and 2.0 degrees C, respectively in calm seas, and 2.2 and 1.9 degrees C. respectively in rough seas. The differences between calm and rough water were not significant for either garment-ensemble.

TABLE 6. MEAN DECLINE IN BACK SKIN TEMPERATURE FOR SUBJECTS WEARING ANTI-EXPOSURE GARMENT-ENSEMBLES IN CALM VS ROUGH SEAS

Garment	Back Temperature Decline (°C + S.D.) Calm	Rough	p*	n**
Flight Suit	17.52 ± 2.95	18.41 ± 1.02	0.472	7
Float Coat	8.69 ± 4.90	17.14 ± 2.54	0.001	8
Boatcrew Coveralls	8.47 ± 3.79	15.11 ± 1.98	0.008	8
Shorty Wet Suit	8.36 ± 2.14	7.29 ± 1.92	0.334	7
Aviation Coveralls	5.75 ± 3.01	10.08 ± 5.32	0.084	6
Wet Suit	5.36 ± 0.88	9.27 ± 0.59	0.001	8
Dry Suit	2.83 ± 1.11	2.22 ± 1.12	0.232	8
Survival Suit	1.98 ± 1.13	1.91 ± 1.84	0.940	7

*p-value from paired t-statistic for calm vs rough seas comparisons

**n=number of subjects; n<8 indicates missing calm seas data and subsequent deletion of corresponding rough seas data for pairwise comparisons.

Figure 26 shows a comparison of the mean decrease in groin skin temperature in calm seas for the eight garment-ensembles, arranged in rank order from highest to lowest. It also shows the results of all pairwise comparisons of the skin temperature declines among garment-ensembles for statistically significant differences ($p < .05$). The flight suit and float coat produced the largest decreases in groin skin temperature among the garments tested, but no significant difference was found between them. Both, however, produced significantly larger declines than

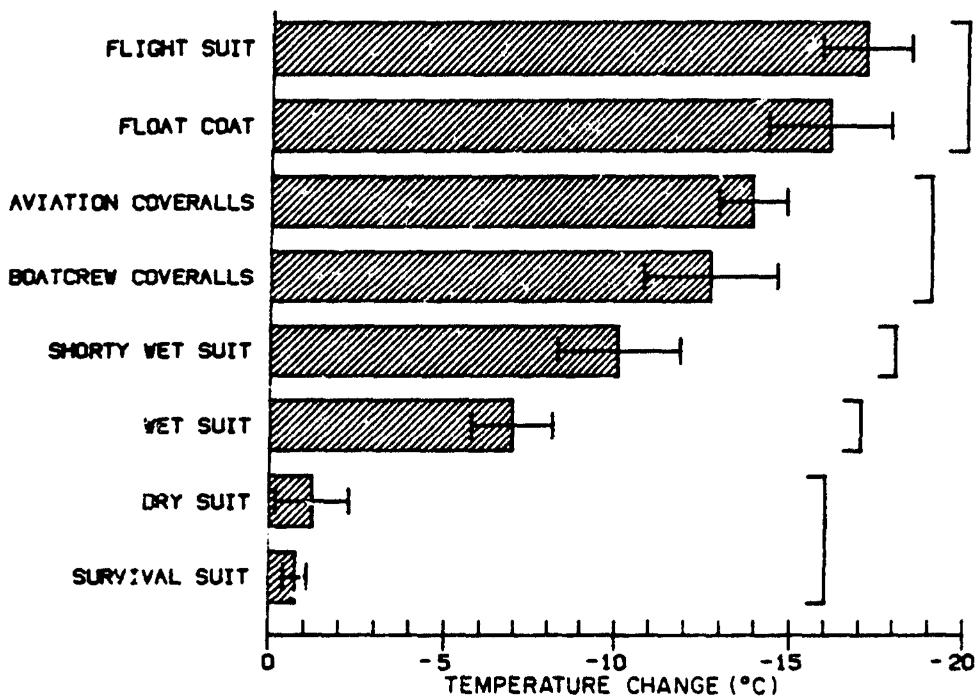

Figure 26.

Intergarment comparison of mean decline in groin skin temperature in calm seas. Vertical bars indicate groups of garments with statistically similar mean temperature declines (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

did any of the other six garment-ensembles. Similarly, no significant difference was found in the decrease of groin skin temperature between the two types of coveralls, but each was significantly larger than the shorty wet suit, wet suit, dry suit or survival suit. Subjects wearing the shorty wet suit had groin temperature decreases which were significantly larger than the wet suit, dry suit and survival suit, and subjects wearing the wet suit had groin temperature declines significantly larger than did subjects wearing either the dry suit or survival suit. These latter two garment-ensembles produced similar decreases in groin skin temperatures in calm seas. There was no significant difference between them, but each was significantly smaller than that found in any of the other six garment-ensembles.

Figure 27 shows a similar comparison of back skin temperature decreases in calm seas for the eight garment ensembles, again arranged in rank order from highest to lowest. Pairwise comparisons of these temperature declines for significant differences showed three major groups. The first consisted of only the flight suit. It produced the largest decrease in back skin temperature, and this decrease was statistically significantly larger than that found for any of the other garment-ensembles tested. The float coat, shorty wet suit, wet suit and both types of coveralls comprised a second group of garment-ensembles with no significant differences among them for back skin temperature declines in calm water. Each of these five garment-ensembles, however, produced a significantly larger decline than did the dry suit or survival suit. These latter two garment-ensembles comprised the last group; there was no significant difference in back temperature response between these two garment-ensembles, and each produced significantly smaller declines than did any of the other six garment-ensembles.

Figure 28 shows the comparison of groin skin temperatures in rough seas, arranged in rank order from highest to lowest. Pairwise comparisons among the eight garment-ensembles again showed three distinct groups with respect to significant differences. Subjects wearing the float coat, flight suit or either type of coveralls had the largest mean declines in groin skin temperatures, but there was no statistically significant difference among them. Each, however, was significantly larger than the remaining four garment ensembles. Subjects wearing the shorty wet suit or wet suit in rough seas had virtually identical groin temperature declines which were significantly larger than found for subjects wearing either the dry suit or survival suit. Subjects wearing these latter two garment-ensembles again had not only similar decreases in groin skin temperature but each was also significantly smaller than found for subjects wearing any of the other six garment-ensembles.

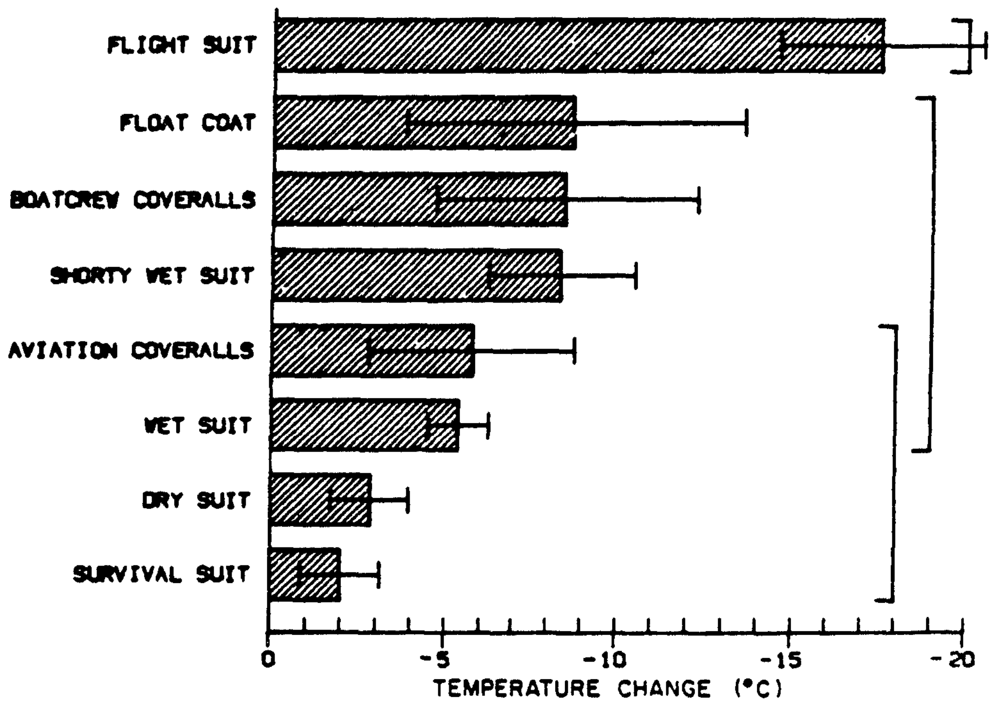

Figure 27.
Intergarment comparison of mean decline in back skin temperature in calm seas. Vertical bars indicate groups of garments with statistically similar mean temperature declines (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

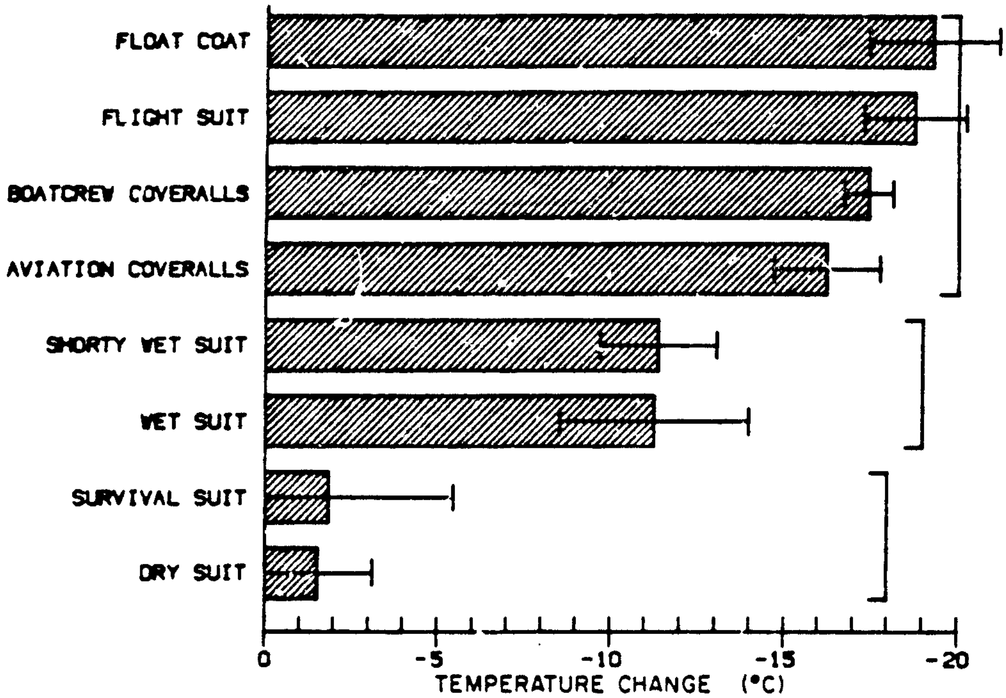

Figure 28.
Intergarment comparison of mean decline in groin skin temperature in rough seas. Vertical bars indicate groups of garments with statistically similar mean temperature declines (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

Finally, Figure 29 shows a comparison of mean decrease in back skin temperatures among the garment-ensembles in rough seas, arranged in rank order from highest to lowest. Subjects wearing the flight suit, float coat of boatcrew coveralls had the largest mean declines, and there was no significant difference between any pair of these three garment-ensembles. The flight suit and float coat each produced significantly larger declines in back skin temperature than did any of the other six garment-ensembles. No difference was found, however, between the boatcrew and aviation coveralls. The boatcrew coveralls produced significantly larger decreases in mean back skin temperature than did either the wet suit, shorty wet suit, dry suit or survival suit. No significant differences were found in back temperature decreases among the aviation coverall, wet suit or shorty wet suit, but each produced significantly larger declines than did the dry suit or survival suit. Subjects wearing the dry suit or the survival suit had significantly smaller back temperature decreases in rough seas than did subjects wearing any of the other six garment-ensembles, but there was no significant difference in back temperature decline between the dry suit and survival suit.

Significant correlations were found between rectal temperature cooling rates and declines in both back and groin skin temperatures. The mean correlation coefficient (r) among the eight subjects for cooling rate vs decline in back skin temperature was 0.78 ± 0.21 in calm water ($p < 0.05$ for six of the eight individual subjects) and 0.84 ± 0.13 in rough water ($p < 0.05$ for seven of the eight individual subjects). The mean correlation coefficient among subjects for cooling rate vs decline in groin skin temperature was 0.73 ± 0.12 in calm water ($p < 0.05$ for seven of the eight individual subjects) and 0.80 ± 0.10 in rough water ($p < 0.05$ of seven of the eight individual subjects).

Heart Rates

Figure 30 shows the heart rate responses for several subjects, which illustrate the typical findings for heart rate changes during this study. Table 7 shows the mean heart rates of the subjects during immersions in calm and rough seas. For each of the garment-ensembles, heart rates were statistically significantly higher in rough-water than in calm-water. The lowest mean heart rate was 69 beats per minute and occurred in subjects wearing the survival suit and lying still in calm-water. The highest mean heart rate was 108 beats per minute and occurred in subjects wearing the float coat in rough-water.

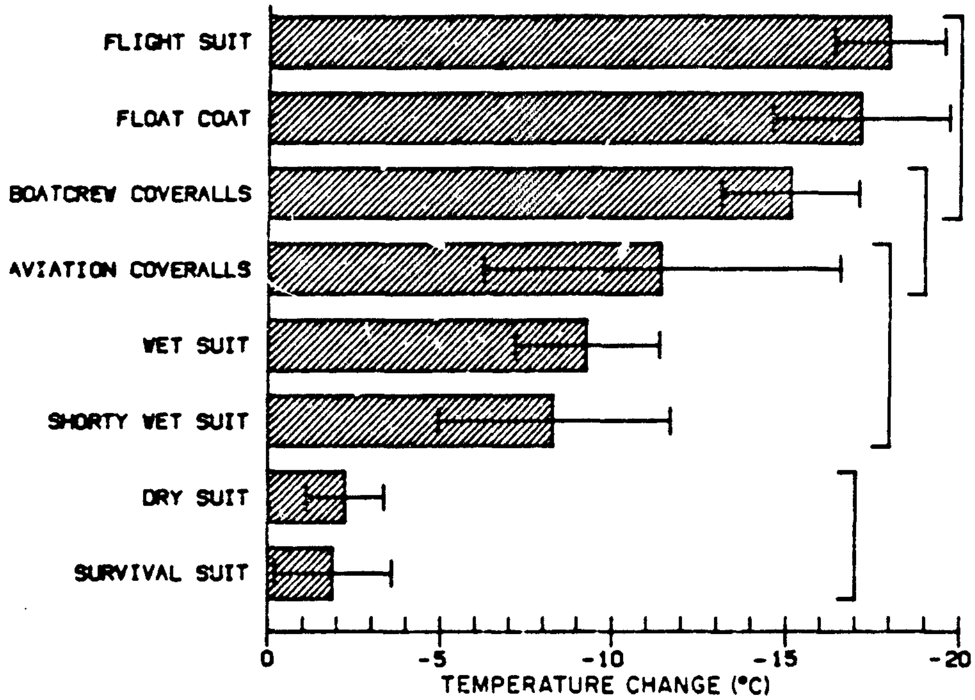

Figure 29.

Intergarment comparison of mean decline in back skin temperaure in rough seas. Vertical bars indicate groups of garments with statistically similar mean temperature declines (per Tukey's multiple comparison test, alpha = 0.05). Horizontal bars indicate sample standard deviations.

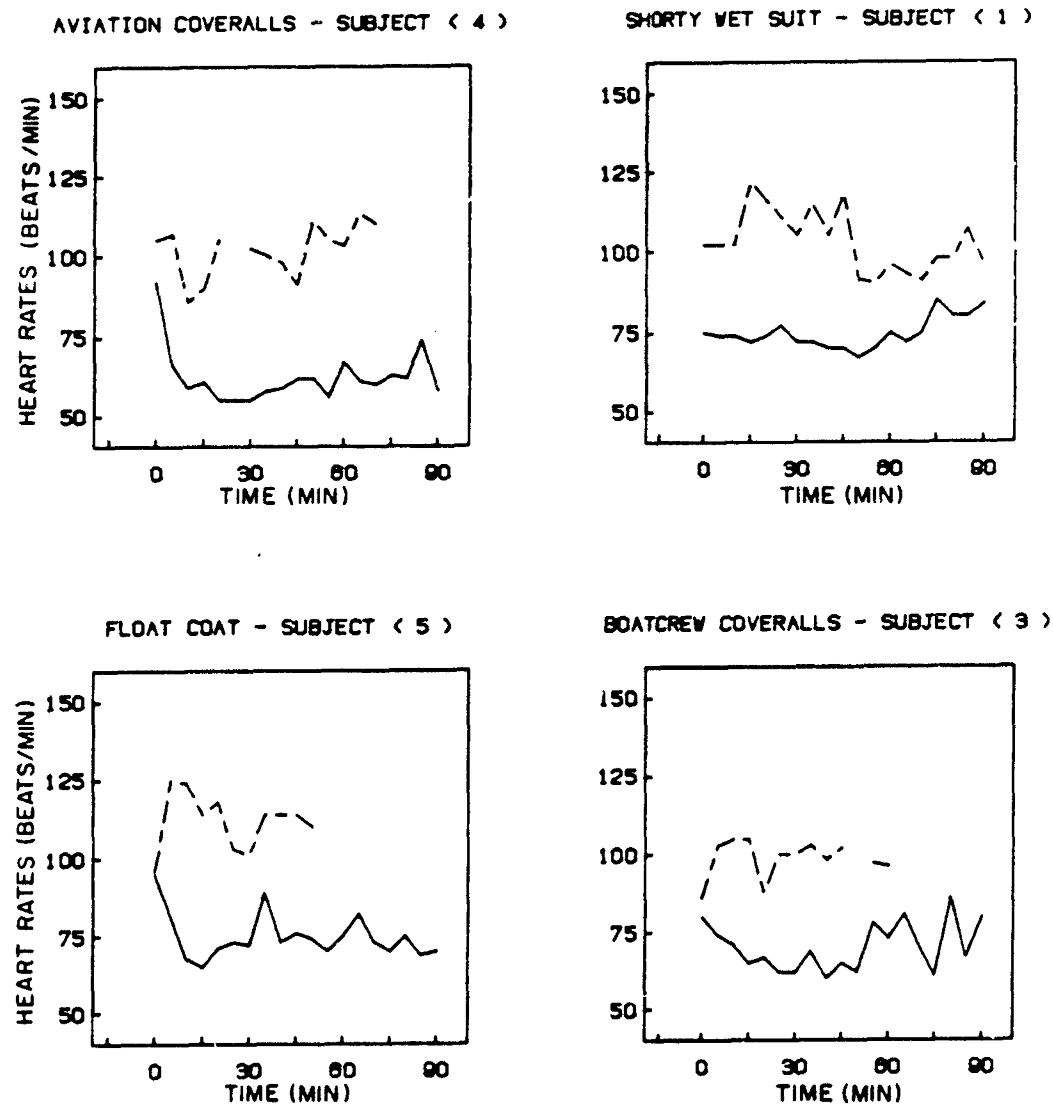

Figure 30.
Heart rate changes (beats/min) for selected subjects and selected garments in calm (———) vs rough (– – – –) seas.

The overall F-test for inter-garment comparisons showed a significant difference among calm water mean heart rates but not among rough water mean heart rates.

TABLE 7. MEAN HEART RATES FOR SUBJECTS WEARING ANTI-EXPOSURE GARMENT ENSEMBLES IN CALM VS ROUGH SEAS

Garment	Heart Rate (beats/min + S.D.) Calm	Rough	p*	n**
Flight Suit	84 ± 10	104 ± 22	.047	7
Float Coat	81 ± 7	108 ± 6	.0001	7
Shorty Wet Suit	74 ± 9	103 ± 9	.0001	8
Dry Suit	74 ± 7	100 ± 14	.002	7
Aviation Coveralls	73 ± 10	97 ± 14	.001	8
Boatcrew Coveralls	73 ± 13	95 ± 12	.001	8
Wet Suit	73 ± 9	101 ± 19	.004	8
Survival Suit	69 ± 8	91 ± 6	.0001	7

*p-value from the paired t-statistic for calm vs rough seas comparisons

**n=number of subjects; n<8 indicates missing calm seas or rough seas data and subsequent deletion of corresponding rough or calm seas data, respectively.

Subjective Evaluations

Tables 8 and 9 show the subjective evaluations and the corresponding cooling rates for each garment-ensemble in calm and rough seas, respectively. The garment-ensembles are listed in rank order of cooling rate from highest to lowest. The values shown for the subjective evaluations of tightness of fit, flushing of cold water and warmth are the mean scores (± S D.) for the eight subjects. Scoring of each attribute was on a scale of 0 (least) to 10 (most). Because these data may have included subject bias for or against certain of the garments, which may have affected the data's quality compared to the quality of the objective measurements of temperatures and heart rates, presentation of results was limited to simple description without

statistical inference and to correlations among means. Nevertheless, the data demonstrate a relationship between certain of the garments' design characteristics and their degree of hypothermia protection (as indicated by subject cooling rates).

TABLE 8. SUBJECTIVE EVALUATIONS* AND COOLING RATES FOR ANTI-EXPOSURE GARMENT ENSEMBLES IN CALM SEAS

Garment	Mean Cooling Rate (°C/hr + S.D.)	Tightness of Fit	Flushing of Cold Water	Warmth
Flight Suit	3.19 ± 1.11	2.2 ± 1.7	9.1 ± 1.7	0.8 ± 0.7
Float Coat	1.61 ± 0.64	6.0 ± 2.5	7.4 ± 1.4	3.4 ± 1.2
Shorty Wet Suit	1.22 ± 0.35	9.0 ± 0.9	3.4 ± 1.6	6.1 ± 1.1
Aviation Coveralls	1.00 ± 0.37	6.9 ± 1.0	4.3 ± 2.4	7.4 ± 1.1
Boatcrew Coveralls	0.98 ± 0.33	5.4 ± 1.7	4.9 ± 1.6	6.9 ± 1.2
Wet Suit	0.66 ± 0.27	7.3 ± 1.4	3.6 ± 1.1	7.0 ± 1.5
Dry Suit	0.67 ± 0.17	6.9 ± 1.6	1.1 ± 1.4	8.9 ± 1.1
Survival Suit	0.50 ± 0.31	3.8 ± 1.3	0.1 ± 0.4	9.3 ± 0.5

*Rating scale = 0 (least) to 10 (most); mean of eight subjects (± S.D.)

In calm water the flight suit and float coat had the largest amount of cold-water flushing (9.1 and 7.4, respectively) and the lowest ratings of warmth (0.8 and 3.4, respectively). On the other hand, the dry suit and the survival suit had the smallest amount of cold-water flushing (1.1 and 0.1, respectively) and the highest ratings for warmth (8.9 and 9.3, respectively). The two types of coveralls and the two types of wet suits had intermediate rating values for flushing of cold-water (range: 3.4 - 4.9) and for warmth (range: 6.1 - 7.4). The tightest fitting garments were the shorty wet suit (9.0) and the wet suit (7.3). The loosest fitting garments were the flight suit (2.2) and the survival suit (3.8). The remaining garments had rating values for tightness- of-fit ranging between 5.4 and 6.9. Among all the garments in calm seas, mean cooling rates were positively correlated with flushing of cold water ($r=0.87$) and negatively correlated with subjective ratings of warmth ($r=-0.94$). Furthermore, among the six "wet" garments, cooling rates were negatively correlated with tightness-of-fit ($r=-0.81$), and tightness-of-fit was negatively correlated with flushing of cold water ($r=-0.88$). The correlations were all significant at $p <$

0.05. In the latter correlations, the six "wet" garments were differentiated from the two "dry" garments (e.g. the dry suit and the survival suit) because the "dry" garments are designed to exclude water entry and do not rely upon tightness-of-fit for their insulation.

TABLE 9. SUBJECTIVE EVALUATIONS* AND COOLING RATES FOR ANTI-EXPOSURE GARMENT-ENSEMBLES IN ROUGH SEAS

Garment	Mean Cooling Rate (°C/hr + S.D.)	Tightness of Fit	Flushing of Cold Water	Warmth
Flight Suit	3.59 ± 1.38	2.3 ± 1.5	9.4 ± 0.9	1.6 ± 2.7
Float Coat	2.40 ± 0.77	5.6 ± 3.0	7.4 ± 2.3	3.0 ± 2.3
Boatcrew Coveralls	1.96 ± 0.69	5.2 ± 1.1	7.5 ± 1.6	5.5 ± 1.6
Aviation Coveralls	1.80 ± 0.56	6.2 ± 2.3	6.8 ± 2.1	6.5 ± 0.5
Shorty Wet Suit	1.33 ± 0.47	8.8 ± 1.2	3.5 ± 1.9	6.8 ± 1.4
Wet Suit	0.91 ± 0.31	7.1 ± 1.4	4.8 ± 1.0	6.2 ± 0.8
Dry Suit	0.49 ± 0.23	6.3 ± 2.1	1.2 ± 0.7	8.9 ± 0.6
Survival Suit	0.41 ± 0.21	3.5 ± 1.3	0.8 ± 0.4	9.3 ± 0.5

*Rating scale = 0 (least) to 10 (most); mean of eight subjects (± S.D.)

In rough seas the flight suit again had the largest amount of cold water flushing (9.4) and the lowest rating for warmth (1.6). The dry suit and survival suit again had the smallest amounts of flushing (1.2 and 0.8, respectively) and the highest ratings for warmth (8.9 and 9.3, respectively). The shorty wet suit allowed a relatively small amount of cold water flushing in rough seas (3.5) which was virtually identical to its performance in calm seas. In addition, its ratings for warmth were nearly the same in both calm and rough seas. These similarities correlated well with the near-equal cooling rates of subjects wearing the shorty wet suit in either sea state. The wet suit also had a relatively small amount of cold water flushing in rough seas, but this was still higher than that found in calm seas (4.8 vs 3.6). Consequently its ratings for warmth were lower in rough seas than in calm seas (6.2 vs 7.0). And the mean cooling rates of subjects in the wet suit were slightly (although

not statistically significantly) higher in rough seas than in calm seas. Both the boatcrew coveralls and the aviation coveralls allowed more cold water flushing in rough seas (7.5 and 6.8, respectively) than in calm seas (4.9 and 4.3, respectively) and each also had lower ratings for warmth in the rough-water vs calm-water conditions (5.5 vs 6.9, respectively for the boatcrew coveralls and 6.5 vs 7.4, respectively for the aviation coveralls). Cooling rates were significantly higher in rough seas than in calm seas for both these garment-ensembles. The float coat had equal ratings of cold water flushing in both rough and calm seas (7.4), and it had only a slightly lower rating for warmth in rough seas (3.0) than in calm seas (3.4). Cooling rates for all the garments in rough seas were again positively correlated with flushing of cold-water ($r=0.93$) and negatively correlated with ratings for warmth ($r=-0.95$). Among the six "wet" garments, cooling rates were again negatively correlated with tightness-of-fit ($r=-0.90$), and tightness-of-fit was again negatively correlated with flushing of cold water ($r=-0.97$). The correlations were all significant at $p < 0.05$.

Additional Covariates

Pre-immersion rectal and skin temperatures, time of day, and ambient water temperature were ruled out as influential covariates on the basis of graphic display, magnitude and variability. In addition, neither day of immersion over the course of the study nor the use of boatwake to generate rough-water conditions significantly affected the pooled error estimates or garment groupings associated with the repeated measures analyses.

DISCUSSION

The results show a significant difference in the amount of protection provided by certain types of anti-exposure garment-ensembles between calm and rough seas. The results als show significant differences among various types of anti-exposu garment-emsembles in both calm and rough seas. The differences in garment performance between the two sea conditions and the differences among garment-ensembles in each of the sea conditic both result from variations in certain design features of the garment-ensembles: 1) "wet" vs "dry" insulation characteristics of the garment; 2) amount of inherent insulation in the garment 3) tightness-of-fit of the "wet" garments and subsequent amount of cold-water flushing; 4) buoyancy of the garment-ensemble; ar 5) flotation posture of the subjects in the garment-ensemble. The following discussion relates the specific findings of this study to these various parameters.

Differences in skin temperatures among subjects wearing tl various garment-ensembles resulted from differences in amount (inherent insulation, in tightness-of-fit, in flotation posture and in "wet" vs "dry" characteristics. Since the majority of heat loss during immersion hypothermia is from the skin (24,25) maintenance of skin temperature is an important feature for a survival garment. In this study, as in previous studies on protective garments (1,7), differences in skin temperatures wei found to be directly related to differences in rectal temperati cooling rates. The flight suit ensemble had the least amount (inherent insulation of the garments tested. It consisted of cotton thermal "long-johns" which became quickly soaked on immersion and which therefore lost most of its insulative properties (2,26). Subjects wearing the flight suit consequen had the lowest mean skin temperatures and the highest mean cooling rates among all the garment-ensembles in both calm and rough seas. This confirmed the findings of previous studies of flight suit performance in cold water (1,6,7). Not surprising these subjects also felt the coldest in both sea states. In ca seas subjects wearing the flight suit had the highest mean hea rates, no doubt reflecting the higher metabolic requirements imposed by the rapid rate of heat loss. In rough seas these subjects had even higher mean heart rates (second only to subjects wearing the float coat), due not only to high cooling rates (27,33) but also, to a small degree, to the physical activity required to maintain airway freeboard. Although the flight suit ensemble provided a relatively large amount of net buoyancy (12.3 kg), its floatation posture was vertical, thus facilitating occasional bobbing movements in waves (28) and

forcing the subjects to actively use their arms and legs to stay above the surface. Subjects wearing the flight suit had similar mean cooling rates in calm and rough seas.

An analysis of the performance of the "wet," foam-insulated garments is facilitated by grouping them into categories of tight-fitting (wet suit and shorty wet suit) and loose-fitting (float coat, boatcrew coveralls and aviation coveralls) garment-ensembles. In both calm and rough seas, the two wet suits maintained the tightest fit, as indicated by the results of the subjective evaluations shown in Tables 8 and 9. Accordingly, they also allowed the least amount of cold-water flushing in both sea conditions. The tight fit and small amount of cold-water circulation within the wet suit and shorty wet suit allowed the subjects to maintain higher groin skin temperatures in these garments than in any of the looser fitting "wet" garments in either rough or calm seas, and they allowed the subjects to maintain higher back skin temperatures in rough seas than in any of these other garments. Consequently rectal temperature cooling rates were lower in the shorty wet suit and wet suit than in the float coat or in either of the two types of coveralls.

The contributions of both inherent insulation and tightness-of-fit to hypothermia protection are shown by comparing the shorty wet suit with the two-piece full wet suit. Although both garments were custom-fitted, the subjects rated the shorty wet suit as tighter fitting than the full wet suit. The shorty wet suit had 1/8" closed-cell foam insulation throughout; the full wet suit had 3/16" closed-cell foam insulation throughout. However, in the groin region, the two-piece wet suit provided a double thickness of insulation (3/8") because of the overlap of the upper section's (3/16") beavertail over the (3/16") trousers. This thicker groin insulation resulted in significantly higher skin temperatures at that site in calm water for the wet suit than for the shorty wet suit. Flushing of cold water in calm seas was minimal in either garment. In rough water, however, flushing of cold water was rated as higher in the wet suit than in the shorty wet suit. The net result was that, despite thicker groin insulation in the wet suit, groin skin temperatures in rough seas were not significantly different from those of the shorty wet suit. Furthermore, back skin temperatures in rough seas were higher in the shorty wet suit than in the full wet suit (although the difference was not significant) despite thicker foam insulation in the back of the latter garment. A greater of amount of cold water flushing in the full wet suit again presumably accounted for this finding.

Among the loose-fitting "wet," insulated garment-ensembles, similar analyses illustrate the importance of thickness of insulation, tightness of fit, etc. in the garment-ensembles'

performance. The two types of coveralls were different in both thickness and distribution of insulation and also in tightness of fit. Even though each garment was fitted as closely as possible to each subject, the boatcrew coveralls were available in five sizes compared to the sixteen sizes available for the aviation coveralls. This presumably accounted for the difference in ratings for tightness-of-fit. Despite these differences, the boatcrew and aviation coveralls performed almost identically in both the calm and rough sea conditions. No significant differences were found in any of the temperature measurements between these two garment ensembles, nor were differences found in heart rate measurements. The aviation coveralls evidently compensated for thinner insulation with a tighter fit and lesser amount of cold-water flushing.

The float coat had thinner insulation than the boatcrew coveralls but thicker insulation anteriorly than the aviation coveralls. Its ratings for tightness- of-fit were also intermediate between the two types of coveralls. The float coat ensemble, however, provided far less buoyancy than did either of the coveralls (and, in fact, far less buoyancy than did any of the other garment-ensembles tested). This diminished bouyancy required the subjects to expend an increased amount of physical exertion in rough seas to maintain airway freeboard. This increased effort was reflected in the subjects' mean heart rates, which were the highest of all the garment-ensembles tested in rough seas. Furthermore, the flotation posture of the subjects in the float coat was vertical. The flotation posture of the subjects in either of the coveralls was more horizontal. Consequently vertical bobbing motions in the float coat were facilitated in rough seas, resulting in an increased amount of cold water flushing. Cooling rates of subjects in the float coat were subsequently higher than in any of the other "wet," insulated garment-ensembles, although the differences from the two types of coveralls were not significant.

The survival suit and dry suit, both designed to exclude skin contact with cold water, maintained significantly higher skin temperatures in rough seas than did any of the other six garment-ensembles. Despite having thinner closed-cell foam insulation than the boatcrew coveralls and similar thickness of insulation to the wet suit, both the survival suit and dry suit maintained higher skin temperatures at both the groin and back sites than did these other garments. This finding again illustrates the importance of cold-water flushing to thermal performance. Neither "dry" garment allowed appreciable cold-water entry compared to the amount of flushing permitted by the "wet" garments. Consequently rectal temperature cooling rates were significantly lower in the survival suit and dry suit in rough seas than in all the other garment-ensembles except the

wet suit. Furthermore, because the "dry," insulated garments excluded cold-water entry, tightness-of-fit was not an important factor in thermal performance.

The "dry" garments in this study were both of the foam-insulated type. Other "dry" protective garments, which have little inherent insulation themselves but rely instead on various layers of insulated undergarments, have previously been shown to be as effective as the foam-insulated types in protection against hypothermia in cold-water immersion (1,6). These garments were not evaluated in this study since they are not presently part of the Coast Guard's inventory of protective clothing.

The flotation posture of the survival suit and dry suit differed from those of the other garment-ensembles in this study. Both "dry" garments maintained the subjects in a horizontal posture, although the dry suit could be forced into a more vertical posture with effort. The horizontal position resulted from the relatively large amount of buoyancy in the lower extremities provided by these garments. This buoyancy derived not only from the inherent properties of the closed-cell foam insulation but also from variable amounts of trapped air between the subject and the garment. Horizontal flotation postures are not optimum for prolonged survival (28) since this position not only allows waves to break over a survivor's face but also facilitates rolling moments in very heavy seas. Neither problem was significant in this study since heavy seas were deliberately avoided for reasons of safety. However, when occasional breaking seas were encountered in the testing area, especially when boat-wakes were used to generate rough seas, subjects in the survival and dry suits did take water over their faces in some instances.

The effects of cold-water flushing were depicted graphically in Figure 23, p. 44. Four rough- vs calm-water comparisons of skin temperature changes are shown for various "wet," foam-insulated garment-ensembles. In each case the rough-water curves show a greater amount of variation than do the corresponding calm-water curves. Rising skin temperatures reflect warming of the skin site and the surrounding water by a subject's body heat, a situation possible only when cold-water flushing is minimized. Rapidly falling skin temperatures reflect cooling of the skin site potentiated by cold-water flushing. Movement of a subject's body, either passively by wave action or actively to maintain airway freeboard, increased cold-water flushing and resulted in the variations in skin temperatures shown. In calm seas the subjects held still. Consequently flushing was minimized and rapid changes in skin temperature were infrequent.

The elevation in mean heart rates observed across all garments for the subjects in rough water was consistent with the increased activity levels required to maintain stable body posture and airway freeboard. Increased rough-water heart rates were also consistent with the increased cooling rates observed for the loose-fitting, "wet" garment-ensembles. In calm water, slightly elevated heart rates were observed in those garment-ensembles with the least inherent insulation (e.g. the flight suit and float coat).

Evidence of acclimitization to the cold water did not occur over the course of a subject's sixteen immersions. With water conditions considered separately, covariate analysis showed no significant relationship between rectal temperature cooling rates and date of immersion.

Estimates of survival times based on the mean rectal temperature cooling rates measured in this study provide another way of comparing the different garment-ensembles in calm vs rough seas. Such projections must be made with extreme caution, however, since the subjects of this study were not representative of either the normal Coast Guard population nor of the general U.S. population. The subjects were all male, so extrapolations to a female population should be made with caution. Some studies, however, have shown that men and women have similar cooling rates (29,30). The subjects also were more physically fit, better swimmers and had less body fat than the normal population of Coast Guard or U.S. men. Physical fitness has been shown to be negatively correlated with cooling rate (and therefore positively correlated with survival time) (31). Likewise percent body fat has been shown to be negatively correlated with cooling rate (32-35). Finally only one water temperature was represented in this study, therefore projections of survival times cannot be reliably extrapolated to other water temperatures. It is reasonable to assume, however, that for the subjects of this study, cooling rates would be higher in colder water and lower in warmer water. Survival times would accordingly be shorter or longer, respectively (30,36).

Given these constraints, estimated survival times for the subjects of this study in 10.7 - 11.1 degrees C. sea water in either calm or rough seas are shown in Table 10. The assumptions underlying the estimations are as follows: 1) Cooling rates are linear starting at 15 minutes from water entry, as other studies have assumed (1,7,29,30); 2) Beginning rectal temperature is 37.5 degrees C; 3) In calm seas, death is secondary to cardiac arrest at a core temperature of 25 degrees C. (37,38) for survivors wearing any of the eight garment-ensembles; 4) In rough seas, death is secondary to cardiac arrest at a core temperature of 25 degrees C. for survivors wearing garment-ensembles possessing

self-righting buoyancy (i.e. flight suit, wet suit, shorty wet suit, and aviation coveralls). For garment-ensembles lacking self-righting buoyancy (i.e. boatcrew coveralls, float coat, dry suit and survival suit), death in rough seas is due to drowning secondary to hypothermia-induced unconsciousness at a core temperature of 30 degrees C; 5) Survivors are actively able to maintain airway freeboard in rough seas in all of the garment-ensembles until unconsciousness occurs at a core temperature of 30 degrees C; below 30 degrees C., airway freeboard is maintained passively in garment-ensembles with self-righting buoyancy. 6) The mean survival times (shown with their 95% confidence ranges) were based on extrapolations of the cooling rates for each subject.

TABLE 10. ESTIMATED SURVIVAL TIMES FOR TEST SUBJECTS WEARING VARIOUS ANTI-EXPOSURE GARMENT-ENSEMBLES IN CALM AND ROUGH SEAS AT 10.7 - 11.1 DEGREES C.

	Estimated Survival Times (hours)* (with 95% confidence range)		
Garment	Calm	Rough	
Flight Suit	3.7 ± 0.8	3.6 ± 1.5	
Float Coat	7.9 ± 2.6	4.8 ± 1.2	(2.9 ± 0.7)**
Shorty Wet Suit	9.7 ± 1.6	9.5 ± 2.8	
Aviation Coveralls	12.6 ± 3.3	6.6 ± 1.1	
Boatcrew Coveralls	13.1 ± 3.3	6.1 ± 1.2	(3.7 ± 0.7)**
Wet Suit	18.1 ± 3.8	15.0 ± 5.7	
Dry Suit	19.8 ± 5.0	30.1 ± 10.5	(18.1 ± 6.3)**
Survival Suit	22.7 ± 9.2	25.4 ± 5.4	(15.2 ± 3.2)**

*Estimated times to assumed cardiac arrest at a core temp. of 25 C.

**Estimated times to assumed loss of consciousness in rough seas at a core temp. of 30 °C. Since these garments are not usually worn with a self-righting life-jacket, drowning is assumed to occur with unconsciousness.

The survival times shown in Table 10 are based primarily on survivor cooling rates and secondarily on buoyancy considerations. Other factors, however, are often as important in affecting sea survival and chances for rescue. Among these

are: 1) water temperature; 2) wind and sea conditions; 3) survivor's body dimensions and percent fat; 4) physical fitness; 5) experience in open-seas swimming; 6) survival training; 7) availability of a life-raft; 8) availability of signalling devices; and 9) mental attitude (e.g. "will to survive"). The survival times shown, therefore, must be interpreted carefully, bearing in mind not only the effects of these other factors but also the constraints imposed by the specificity of the subject population upon which the estimates are based.

CONCLUSIONS

1) Loose-fitting, "wet", foam-insulated protective garments (e.g. the float coat, aviation and boatcrew coveralls) allow lower skin temperatures and faster rectal temperature cooling rates in rough seas than in calm seas because they permit significant cold-water flushing within the garment in the rough sea conditions.

2) Tight-fitting, "wet", foam-insulated protective garments (e.g. the custom-fitted full wet suit and the custom-fitted shorty wet suit) provide equivalent protection in calm and rough seas because they minimize the amount of cold-water flushing within the garment.

3) "Dry", foam-insulated garments provide the best protection in both calm and rough seas, since cold-water is excluded within the garment. Skin temperatures are highest and rectal temperature cooling rates are lowest in these "dry" garments

4) In calm seas, where subjects can remain motionless and where cold-water flushing is minimal, the coveralls and the wet suits provide approximately the same degree of protection. In rough seas, however, the full wet suit provides significantly better protection than do the coveralls.

RECOMMENDATIONS

The results of this study provide information on the comparitive protection against accidental immersion hypothermia provided by various types of anti-exposure garments in calm and in rough seas. It is recommended that this information be considered by both organizations and individuals where protective clothing is required for work in a cold maritime environment.

Protection against accidental immersion hypothermia, however, is only one factor in the selection of appropriate operational clothing. Other important factors which must be considered are the following:

1) Buoyancy
   a. amount
   b. inherent, inflatable or both
   c. self-righting capability
   d. airway freeboard (distance of the nose and mouth from tha water's surface) in both rough and calm seas
   e. reliability
2) Protection of the airway from aspiration of water in rough seas
3) Continuous wear capability
   a. at rest and while working
   b. heat stress
   c. reduction in mobility
   d. maintenance of manual dexterity
   e. comfort
   f. aesthetic appeal
4) Ease of donning and donning-time
5) Visibility and storage space for signalling devices
6) Facility of rescue
7) Facility of underwater escape
8) Flame resistance
9) Maintenance and required storage space
10) User confidence
11) Cost

Protection against immersion hypothermia must be carefully balanced against these other factors, and such balance necessarily involves compromises. Maximum protection against hypothermia, for example, is almost always achieved at the expense of comfort, mobility and reduction of heat stress. It is recommended that the results of this study be used with caution, therefore, to avoid over-emphasis on the cooling rate data from the select population of human subjects used in these experiments.

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RISK/BENEFIT ANALYSIS FOR CALM AND ROUGH WATER TESTING OF VARIOUS ANTI-EXPOSURE GARMENTS

1. Description of the Project: The intent of this project is to determine the difference in cooling rates of human subjects wearing various types of anti-exposure garments in both calm and rough water conditions. Eight garments currently used by Coast Guard operational crewmen or by commercial maritime personnel will be tested. Eight human subjects will each wear each of the garments in both calm and rough water conditions. The subjects will be screened for medical suitability, for physical fitness and for survival swimming skills. The subjects will be fitted with a rectal probe for measuring core temperature, with several skin probes for measuring various skin temperatures, and with EKG leads for monitoring heart rate and rhythm. Each subject will wear a safety line for rapid retrieval by rescue personnel, and each subject will wear an appropriate floatation device. Each subject will remain immersed until his core temperature has declined sufficiently to establish a linear cooling rate (but in no case more than 2 degrees C.), until he voluntarily wishes to terminate the cooling, until his rectal temperature reaches 35 degrees C. (95 degrees F.), or until he is directed to egress the water by one of the project medical officers. In no case will subjects remain immersed longer than ninety minutes. Each subject will then promptly be rewarmed in a warm-water bath.

2. Description of the Risk: This project involves a very small amount of physical risk to the subjects. The risk results from the total immersion of the subjects to a core temperature bordering on mild hypothermia (clinical hypothermia is defined as a core temperature of 35 degrees C. or lower - in no case will a subject be permitted to cool below this temperature in the water). The risk also results from each subject's immersion in rough water and the necessity to actively combat the seas to keep his head afloat. The first few minutes of immersion in cold-water are also often associated with hyperventilation, and, on occasion, ventricular ectopic beats ("skipped" heart beats). Rare, anecdotal cases of ventricular fibrillation have been reported. Subject risks will be minimized by the following:

A. All subjects will be carefully screened for medical suitability, for a high degree of physical fitness, for any tendency to develop ventricular ectopic beats under stress (i.e. maximal exercise stress test), and for confidence in and skill at rough water survival.

B. All subjects will have bouyancy of at least 15 pounds, and in some cases as much as 40 pounds.

C. Each subject will wear a retrieval line during all immersions.

D. Each subject will be monitored for rectal temperature, skin temperatures and for heart rate and rhythm.

E. Designated rescue swimmers will be present during each immersion.

F. At least one medical officer will be present during each immersion.

G. Subjects in rough water will be easily retrievable since a rigid hull inflatable will be on-scene during each immersion.

H. In all cases subjects can be rescued from the water within 30-60 seconds.

The only other method which could be used to obtain similar data would be through the use of a mannequin. This method is not suitable, since mannequins have not yet been developed which duplicate human physiology and since, in the rough water tests, the subjects are required to actively maintain their heads above water. Subjects must also provide their subjective evaluations of the performance of each of the anti-exposure garments in rough water.

The scientists conducting the experiments (CDR A. STEINMAN, COMDT (G-OSR); CAPT M. NEMIROFF, SUPTCEN KODIAK; and Dr. J. HAYWARD, University of Victoria, Victoria, British Columbia) are technically and medically qualified to perform the tests. Each has extensive background in cold-water operations, in the floatation and performance characteristics of the garments to be tested, and in coldwater experimental procedures.

3. <u>Description of the Benefits:</u> This project will provide unique and essential information on the degree of protection afforded by various anti-exposure garments currently used by the Coast Guard, by other branches of the Armed Forces, and by various maritime industries. Previous scientific studies on the cooling rates of human volunteers wearing anti-exposure garments have all been conducted in calm water (either in cooling tanks or in sheltered bodies of water). Most mishaps involving immersion hypothermia, however, usually occur in rough water. A survivor's primary problem in rough seas is keeping his face above the water; hypothermia is only of secondary importance. The struggle to stay afloat, however, may directly influence a survivor's cooling rate. For example, if a survivor's anti-exposure garment requires the maintenance of a trapped, warm layer of water as part of its insulation (e.g. a wet suit), and if the survivor's movements in the water to keep his head afloat result in flushing of this trapped water by ambient cold water, the survivor's cooling rate will probably increase. Furthermore, a survivor coping with a rough sea oftenuses vigorous muscle activity to stay afloat. In so doing he generates metabolic heat. In a cold sea this body heat is quickly lost, again increasing the survivor's cooling rate. The degree to which these increases in cooling rates occur and the degree to which survival time in rough seas is subsequently decreased have never been measured. No scientific studies have yet been performed on the difference in cooling rates in various protective garments between calm and rough water conditions.

The information obtained from this study will directly benefit Coast Guard operational crews who urrently use the tested garments. The results of this study will improve survival training procedures and will affect crew confidence in the use of these items of survival equipment. This project will also provide information on the performance characteristics in rough water of each of the tested garments. This information is also of interest to Coast Guard personnel, to offshore oil rig personnel, and to fishing and other maritime industry personnel who are at risk from accidental immersion hypothermia. The information may also aid in the development of Coast Guard regulations for anti-exposure garments to ensure they function properly in rough water. And the data may benefit anti- exposure garment manufacturers in designing new items of protective clothing. The results of these experiments will be published in an appropriate scientific journal, and they will also be made available to the public.

4. Recommendation: Because the risks of this study are minimal and because the benefits are so great, I believe the expected benefits outweigh the risks.

A. M. Steinman

A. M. STEINMAN
CDR, USCG (Project Monitor)

Concur __________ Do Not Concur __________ CAPT J.M. TANGUAY (G-OSR)

Concur __________ Do Not Concur __________ CAPT E. BLASSER (G-KOM)

Concur __________ Do Not Concur __________ Mr. W. LOWRY (G-CSP)

APPENDIX B

Memorandu

U.S. Department of Transportation

United States Coast Guard

Subject USE OF HUMAN SUBJECTS IN TESTING ANTI-EXPOSURE GARMENTS

Date 2 APR 1984

5100
(G-LGL/34)

Reply to Attn of C. Sachs: 426-1

From Chief, General Law Division

To Chief, Search and Rescue Division

1. We have been advised by CDR Steinman of your staff that he is conducting environmental tests to determine the cooling rates and susceptability to heat stress of human subjects clothed in various types of anti-exposure garments used by the Coast Guard, the Armed Services, and maritime industries. He has furnished us with the research and development proposal for this project, as well as a risk-benefit analysis and the consent and disclosure forms that are presented to prospective participants. We have been asked whether there are any legal requirements for such a project, and if so, whether they are being met.

2. The use of human test subjects is essentially not treated within any statute, regulation, DOT Order, or internal directive that applies to the Coast Guard. Under 46 U.S.C. 481, the Secretary is authorized to prescribe rules and regulations for lifesaving equipment that is necessary for vessels subject to inspection and certification by the Coast Guard. Regulations on the approval testing of adult size exposure suits found at 31 CFR 160.071-71 require the use of human test subjects. Paragraph (d)(3) of this regulation requires that a physician be present while the thermal protective capability of an exposure suit is tested. Paragraph (d)(5)(i) provides that the test must be terminated before completion if (i) the physician determines that the subject should not continue, (ii) the subject requests termination due to discomfort or illness, . (iii) the subject's rectal temperature drops more than 2°C below the initial rectal temperature, unless the physician determines that the subject may continue, or (iv) the subject's finger or toe temperature drops below 5°C, unless the physician determines that the subject may continue. The remainder of the regulation is devoted to the performance requirements of the suits being tested, and establish no standards for the use of human subjects.

3. Regulations establishing standards for the use and protectic of human test subjects have been issued by other Federal agencie

SUBJ: USE OF HUMAN SUBJECTS IN TESTING ANTI-EXPOSURE SUITS

3. (Cont'd) Examples include those for the Consumer Products Safety Commission found in 16 CFR 1028, the Department of Energy in 10 CFR 745, the Food and Drug Administration in 21 CFR 50, the Department of Health and Human Services in 45 CFR 46, and the Public Health Service in 42 CFR 2a. In consultation with representatives of the Air Force and the National Highway Transportation Safety Administration, we have learned that agencies conducting research on human subjects generally rely on the HHS standards if they have not issued their own. There is no legal requirement for the HHS standards to be followed, as by their express terms they apply only to "research conducted by the Department of Health and Human Services or funded in whole or part by a Department grant, contract, cooperative agreement, or fellowship. 45 CFR 46.101(a). They may nevertheless provide effective guidelines for other agencies in conducting their own activities. The primary feature of the HHS regulation is that all research involving human subjects must be approved by an Institutional Review Board (IRB) charged with the responsibility for "safeguarding the rights and welfare of human subjects," and determining "the acceptability of proposed research in terms of institutional commitments and regulations, applicable law, and standards of professional conduct and practice." 45 CFR 46.107(a). HHS requires the IRBs to be comprised of individuals representing a variety of professional disciplines. Furthermore, none may have a conflicting interest in the project being reviewed. The NHTSA representative we spoke to indicated that a review committee has been established in that agency with three members, including a medical adviser, an engineer, and a lawyer. Although no formal committee has been established to review your research, you have requested the concurrence of representatives from OSR, KOM and CSP. Given the fact that there is no on-going process within the Coast Guard for conducting tests on human subjects, the concurrence process employed in this instance would appear to be sufficient. The second principal aspect of the HHS regulation is the requirement for the informed consent of research subjects. 45 CFR 46.116. The disclosure statement and consent form that you have submitted for our review appear to satisfy the HHS requirements.

W.A. NICEWICZ

APPENDIX C

CONSENT FORM
FOR VOLUNTEER PARTICIPANTS
IN USCG TESTS OF VARIOUS ANTI-EXPOSURE GARMENTS
IN CALM AND ROUGH WATER

Full Name (Rate/Grade First name, Middle initial, Last name) ____________________

Duty Station ______________________________

1. I, ____, hereby volunteer to partici as a test subject in the USCG tests of various anti-exposure garments in calm and ro water. I understand that I have the right to withdraw from or refuse to participate the testing at any time without prejudice. Similarly, I accept the right of the Coa Guard Project Monitor (CDR STEINMAN) to refuse to use me as a test subject at any ti

2. The implications of my voluntary participation; the nature and duration of the te the methods and means by which it is to be conducted; and the inconveniences and hazards to be expected from the test are stated on the attachment to this agreement, I have read and initialed them. I have been given an opportunity to ask questions concerning this study, and such questions have been answered to my full and complete satisfaction by ____ ________________ .

3. Before I participate in any test, I will receive a physical examination and an exercise stress test. I agree to report to CDR STEINMAN or to CAPT NEMIROFF any cha in my physical condition following my physical examination or during the actual test

4. I agree to allow the photographic recording of my participation, by still or moti pictures or by videotape, if such are required during the tests, and I agree to all the taking of anthropomorphic data (height, weight, and % body fat measurements) wi the understanding that these documentations are the property of the government, and they will be used only for research and educational purposes. I understand that I a not entitled to any monitary benefits now or in the future for use of this material.

________________________ ________________
Signature Date

I was present during the explanation referred to above, as well as during the volunteer's opportunity to ask questions, and I hereby witness his signature.

________________________ ________________
Witness's Signature Date

SPECIFIC IMPLICATIONS OF BEING A VOLUNTEER SUBJECT
FOR THE USCG TESTS OF ANTI-EXPOSURE GARMENTS IN CALM AND ROUGH WATER

1. As a volunteer for these tests you will be helping the Coast Guard evaluate the thermal protection and floatation properties of survival garments currently in wide use in the Coast Guard, in other branches of the military, and in the civilian maritime community.

2. The tests will take approximately 3-4 weeks and will commence on or about 16 April 1984. The following garments will be tested: a) USCG aviation coveralls (flight suit) with inflatable PFD; b) full wet suit (3/16" Neoprene, two-piece model with comfort zippers) with inflatable PFD; c) "shorty" wet suit (1/8" neoprene wet suit covering the trunk, arms and upper thighs and worn underneath a flight suit) with inflatable PFD; d) boatcrew anti-exposure coverall (Stearns Model IFS 580); e) aviation anti-exposure coverall (Mustang Model MAC 10); f) boatcrew insulated float coat (Mustang UVIC Thermofloat): g) boatcrew dry suit (Narwahl) with Type III work-vest PFD; and h) Survival suit (3/16" Neoprene single-piece dry suit from Imperial).

3. You will be asked to wear each of the above garments in both calm and in rough water for a total of 16 immersions. The calm water tests will be conducted at the boat docks at CGSTA Cape Disappoinment, WA. The rough water tests will be conducted off a Coast Guard motor lifeboat in the Columbia River bar region. Sea conditions during the rough water tests will be approximately 6-8' predominantly non-breaking seas with occasional larger swells.

4. During each immersion the following measurements will be recorded: a) rectal temperature; b) skin temperatures from three locations; and c) heart rate and rhythm. The measurements will be made by thermometers and heart rhythm sensors located at appropriate sites and connected by 100' of cable to monitoring instruments aboard the MLB (for the rough water tests) or in the CGSTA Cape Disappointment boat house (for the calm water tests). An immersion may be terminated under any of the following conditions:

a) You wish to discontinue the immersion at any time.
b) You are directed by one of the project medical officers to discontinue the immersion.
c) Your rectal temperature has decreased by 2 degrees C.
d) Your rectal temperature has decreased to 95 degrees F. (35 deg C.). No immersion will last longer than 90 minutes, and you will only be asked to test one garment (i.e. one immersion) per day.

5. Your risks during the immersions are minimal, and they can be divided into three categories: a) lower body temperature (hypothermia); b) drowning; and c) irregular heart beat ("skipped" beats).

Lower body temperature: Immersion in cold water, in most of the test garments, will decrease your body temperature. However, you will not be permitted to cool below a temperature of 95 degrees F., and in most immersions you may not even reach 95 degrees F. during the 90 minute test period. 95 degrees F. is medically considered only very mild cooling with neither short-term nor long-term risks. however, cooling to this temperature can be associated with a great deal of discomfort: maximal shivering, increased heart rate and breathing rate, loss of manual dexterity and coordination, and, of course, a sensation of extreme cold.

Drowning: If you are unable to keep your head above water during the rough water tests, you risk inhaling water and drowning. This risk is extremely small since a) you will be pre-tested for your ability and confidence to handle rough seas; b) you will always be wearing a personal floatation device and a retrieval harness; c) rescue swimmers and a physician will always be on-scene; and d) rough water tests will not be conducted in hazardous sea conditions.

Irregular heart beats: Immersion in cold-water in some people is associated with an irregular heart beat. In extremely rare circumstances these irregular heart beats may cause heart stoppage. Your risk of irregular heart beat is also extremely small since a) you will be pretested on an exercise treadmill for any tendency to develop an irregular heart beat during stress; b) you will be carefully examined to verify your state of good health; c) your heart will be monitored with a heart tracing during all immersions; and d) you will be removed from the water at the direction of one of the on-scene medical officers if an irregular heart beat occurs and is thought to cause you danger.

There have been no injuries, disabilities or deaths among the hundreds of similar previous test immersions conducted by Dr. Hayward, Dr. Steinman or Dr. Nemiroff.

6. During each immersion you will have from 15-40 pounds of buoyancy, depending on the garment being tested. You will be tethered to either the MLB or to the boat docks by a swimmer's harness. The harness will permit your rapid rescue should the need arise. A rescue swimmer will be on-scene during all immersions, and during the rough water tests, a rigid-hull inflatable rescue boat will also be on-scene. At least one medical officer will be present at all times, and medical equipment will be available aboard the MLB and on the boat docks.

7. Following each immersion you will be rewarmed in a circulating, warmwater bath (hot tub) at CGSTA Cape Disappointment. After each calm water immersion, you will be transported by vehicle from the boat docks to the rewarming site. After each rough water immersion, you will be picked up by the rigid hull inflatable rescue boat and transported to shore for further transfer by vehicle to the rewarming site.

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